Centre for
Resource Studies

Queen's University
Kingston, Ontario

Economic Mineral Exploration Targets

BRIAN W. MACKENZIE

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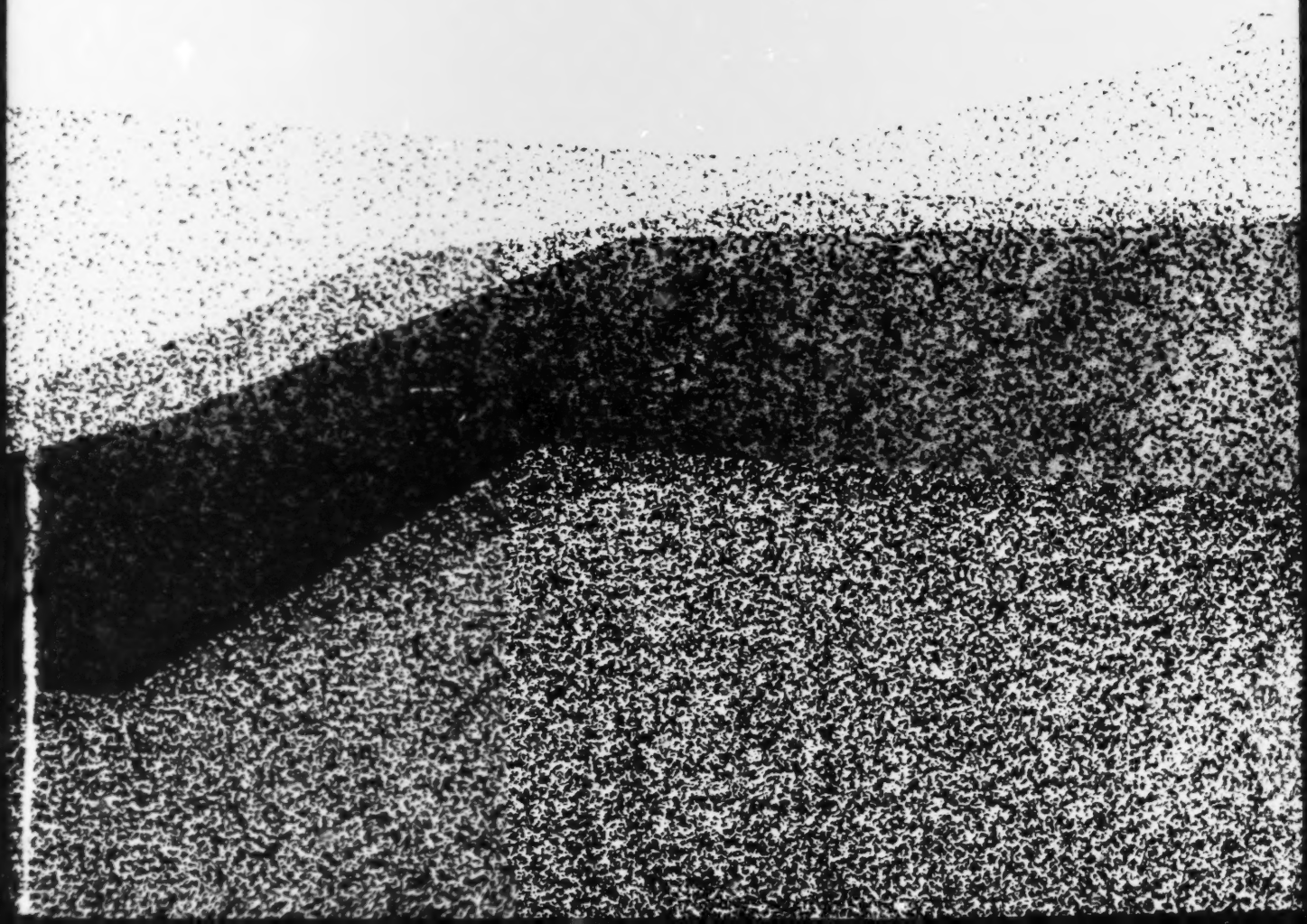

ECONOMIC MINERAL EXPLORATION TARGETS

by

Brian W. Mackenzie

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The support of a large number of Canadian mining companies which, over the past decade, have provided the base metal deposit data which form the basis for this study is gratefully acknowledged.

I would like to thank my colleague Michel Bilodeau, Department of Mining and Metallurgical Engineering, McGill University, for the computer modelling and analysis required for the study. Bob Mason, Department of Geological Sciences, Queen's University, provided useful advice concerning the definition of exploration environments and deposit types.

The paper is one aspect of work in progress on the subject of exploration economics at the Centre for Resource Studies.

FOREWORD

This paper represents research sponsored by the Centre for Resource Studies and aimed at improving knowledge of the Canadian mineral industry and the political and economic environment in which it operates. This study analyzes the geological, cost, price, and taxation determinants of mineral exploration targets, drawing on Canadian exploration experience, and points out an important inefficiency in the Canadian taxation system. It also considers the overall economic justification for the mineral exploration process.

The Centre's working paper series is offered for information and discussion, in an attempt to encourage feedback to the author and additional research in mineral policy. Views expressed are those of the author, and do not necessarily represent those of the Centre or its sponsors.

Margot J. Wojciechowski
Centre for Resource Studies

SUMMARY

Mineral exploration is the starting point of the mineral supply process. It is also the stage involving the greatest degree of risk to the investor. This study develops a method for determining the economic characteristics of exploration targets, using data for 275 significant base metal deposits discovered in Canada to 1977. The data support the conclusion that a large number of economically attractive deposits remain to be discovered, and that the investment incentive overall is not unattractive.

The return from exploration investment can be expected to vary sharply, as a function of such variables as metal price, time trends, exploration environment, and deposit type. For example, other things being equal, gold deposits represent more attractive exploration targets than copper, and copper deposits are more attractive than zinc. A major cause of variation is metal price changes. For example, on the basis of current price expectations, 98 of the 275 known base metal discoveries would be economic if developed today. However, given the spot prices prevailing in January 1983, only 36 of these could be considered economic.

A practical understanding of the economic characteristics of exploration targets is essential for corporate planning and justification of exploration expenditures. It is also essential for development of taxation policies that will optimize the net return to society of its natural resources. The present taxation system in Canada is inefficient, in that it renders uneconomic a significant proportion of the known economic discoveries. This diminishes the long-term potential for the generation of wealth and its distribution in a variety of forms, including personal and corporate income taxes.

RÉSUMÉ

La prospection minérale est le point de départ du processus d'approvisionnement en minerais. Cette étape est aussi celle qui présente le degré de risque le plus élève pour l'actionnaire. La presente étude explique une façon de déterminer les caractéristiques économiques des cibles de prospection, en utilisant les données de 275 gisements metalliferes importants découverts au Canada jusqu'en 1977. Ces donnees prouvent que de nombreaux gisements non encore decouverts offrent des possibilités économiques intéressantes et que, dans l'ensemble, les stimulants à l'investissement sont attrayants.

Les bénéfices des capitaux investis dans la prospection sont appelés à varier brusquement en fonction des variables telles que le prix du métal, le facteur temps et l'emplacement et le type des gisements. Par exemple, à comparaison égale, les gisements d'or constitutent des cibles de prospection plus intéressantes que ceux de cuivre; de même, les gisements de cuivre sont plus avantageux que ceux de zinc. Cette variation est surtout due au changements dans les prix des métaux. Par exemple, en se basant sur les prix actuels, 98 des 275 gisements métallifères connus seraient économiquement rentables si on les exploitait aujourd'hui. Cependant, si l'on se base sur les prix que étaient en vigueur en janvier 1983, seulement 36 de ces gisements seraient rentables.

Une compréhension pratique des caractéristiques économiques des cibles de prospection est essentielle pour la planification des compagnies et la justification des dépenses de prospection. Cela est également très important pour la mise sur pied de politiques fiscales qui vont rapporter à la societé le maximum de bénéfices pour ses ressources naturelles. Le régime fiscal actuel est inefficace puisqu'il empêche à de nombreuses découvertes économiques d'atteindre le seuil de rentabilité. Cette situation diminue, à long term, le potential de production de la richesse et sa distribution sous plusieurs formes, y compris les impôts personnels et corporatifs.

CONTENTS

Acknowledgements / iii

Foreword / iv

Summary / v

Résumé / vi

1 Introduction / 1

2 Methodology and Data Base Employed / 2

3 Economic Characteristics of Exploration Targets / 5
Number of Economic Discoveries / 5
Value of Economic Discoveries / 7
Metal Price Variants / 10
Time Trends / 12
Exploration Environments / 16
Deposit Types / 18

4 Effect of Individual Metals on the Economics of Prospective Exploration Targets / 23

5 Minimum Acceptable Exploration Target Conditions / 26

6 Economic Justification for Exploration / 32
The Case of Base Metal Exploration in Canada / 32
Expected Value of Mineral Exploration / 33
Breakeven Costs and Prices / 37

7 Conclusions / 42

Bibliography / 45

Appendix I: Canadian Base Metal Deposits - Classification by Exploration Environment / 47

Appendix II: Canadian Base Metal Deposits - Classification by Discovery Date / 51

The Author / 55

Centre for Resource Studies / 57

CRS Publications / 58

TABLES

1. After-Tax Value of Economic Discoveries: Key Statistics / 9

2. Long-Term Metal Price Variants / 11

3. Hypothetical Zinc, Copper, and Gold Exploration Targets / 24

ILLUSTRATIONS

1. Relationship of Rate of Return to Cumulative Number of Deposits / 6

2. Number of Economic Deposits After Tax: Cost-of-Capital Variants / 7

3. Relationship of Net Present Value to Cumulative Number of Economic Deposits / 8

4. Average Metal Product Mix: After-Tax Economic Deposits / 10

5. Number of Economic Deposits After Tax: Metal Price Variants / 13

6. Average After-Tax Value of an Economic Discovery: Metal Price Variants / 13

7. Time Trend in the Number of Economic Discoveries After Tax / 15

8. Time Trend in the Average After-Tax Value of an Economic Discovery / 15

9. Average After-Tax Value of an Economic Discovery by Exploration Environment / 19

10. Average Metal Product Mix by Exploration Environment / 19

11. Average After-Tax Value of an Economic Discovery: Deposit Type Variants / 22

12. Average Metal Product Mix: Deposit Type Variants / 22

13. Minimum Acceptable Exploration Target Conditions for Zinc, Copper and Gold Deposits / 27

14. Minimum Acceptable Gold Exploration Target Conditions: Price Variants / 29

15. Minimum Acceptable Gold Exploration Target Conditions: Remoteness Variants / 31

16. Before-Tax Expected Value of Exploration / 34

17. After-Tax Expected Value of Exploration / 36

18. Before-Tax Breakeven Cost and Price Determination / 39

19. After-Tax Breakeven Cost and Price Determination / 40

1. INTRODUCTION

The role of the mining sector in the economy is to find, delineate, and develop economic mineral deposits, and then to mine, process, and market products from them. Thus, economic mineral deposits are the focal point of the whole mining process. The economic characteristics of these deposits are shaped by a number of special geological features. Economic mineral deposits are initially unknown and, once discovered, are fixed in size, variable in quality, and fixed in location.

The mining cycle starts at the exploration stage, where there is not only a long period of investment but also a high risk of total loss through failure to discover an economic deposit. One thing the current prolonged recession in the mining sector is forcing us to acknowledge - as a country, as provinces, as mining companies, and as individuals - is that we need to become more aware of the real nature of mineral exploration from an economic point of view.

This paper focuses on only one element of the sensitive and exciting cost-risk-return relationship which underlies mineral exploration - the return or prize realized as the result of successful exploration. But it is the one positive element which motivates exploration. For this purpose, economic mineral deposits are viewed as exploration targets.

The paper analyzes the geological, cost, price, and taxation determinants of the economic viability of mineral exploration targets. Illustrations are drawn from mineral exploration experience in Canada.

Initially, the methodology and data base employed are briefly outlined. Then, the economic characteristics of mineral exploration targets are evaluated, considering the effects of current taxation systems, changing and uncertain metal prices, the time trends in economic discovery rates and returns, and the traits of particular deposit types and exploration environments. The relative merits of zinc, copper and gold for the economics of prospective exploration targets are next evaluated. Then, minimum acceptable tonnage-grade conditions for economic exploration targets are assessed as a function of commodity, metal price, and remoteness. Finally, considering the time and cost required to find and delineate economic deposits, the overall economic justification for exploration is examined.

2. METHODOLOGY AND DATA BASE EMPLOYED

The case of base metal exploration in Canada is used to examine the characteristics of economic mineral exploration targets. Base metal exploration is considered to include the search for copper, zinc, lead, and molybdenum deposits, together with any associated gold and silver content.

Assessments are based on 275 significant base metal deposits discovered in Canada to 1977. The intention has been to include all known deposits of at least 200,000 tonnes which offer medium-term development potential on the basis of current outlook conditions. These deposits, classified in appendix I by exploration environment and in appendix II by discovery date, represent the overall return or yield from base metal exploration. Most of these deposits have in fact produced, but a significant number still await possible future development. In any case, it is assumed that present-day exploration targets for future discovery resemble, in economic terms, these 275 historical footprints.

A discovery is considered to be made when the deposit which ultimately forms the basis for mine development is first encountered by drilling. Deposits are considered individually if their discovery required essentially independent primary exploration programs.

To be relevant for policy and planning today, each deposit is evaluated on the basis of current economic and technological outlook conditions. All values are expressed in constant mid-1983 dollars.

An economic mineral exploration target is defined as a discovery which realizes a rate of return of at least 8 percent in constant money terms. This 8-percent rate-of-return investment margin has been selected as a best estimate of the weighted average cost of capital for mineral investment funds.

Each of the discoveries is evaluated to assess the cash flow profile associated with its development and exploitation. General market estimates are used to assess the time distribution of revenues for the deposit. These include, most importantly, long-term future price forecasts corresponding to the time frame of the mining cycle being evaluated. The assessment of costs and revenues assumes that metal concentrate is produced at each possible mine. General net smelter return conditions for copper, lead and zinc are used to convert the forecast metal prices to a

revenue estimate for the sale of concentrate at the smelter. Concentrate transportation charges are then deducted to work these payments back to minesite values.

Individual deposit estimates are made by placing actual historical deposit data in the context of today's conditions. Estimates of recoverable ore reserves, ore capacity, preproduction period, preproduction capital cost, the cost of major modifications, sustaining capital, operating costs, metallurgical recoveries, concentrate grades, and concentrate transportation are required for each of the base metal discoveries. In circumstances where there is the opportunity to treat ore from more than one mine in a common processing facility, specifications are also given for a regional mill alternative. In cases where actual historical data are not available, generalized costing relationships are applied, reflecting an order-of-magnitude level of accuracy.

Thus, a time distribution of cash flows is assessed for each of the discoveries. A number of measures of economic worth, including total revenue, rate of return, and net present value, are evaluated for each deposit.[1] Those discoveries which satisfy the 8-percent minimum acceptable rate of return condition are considered to be economic deposits, thus representing economic mineral exploration targets.

Assessments are initially made on a potential value or before-tax basis, including all direct costs and revenues. This evaluation represents the worth of economic exploration targets to society, prior to taxation considerations, and reflects the fundamental value of mineral endowment. Then, relevant mining taxation systems are applied to the potential values. This after-tax assessment addresses the question of investment incentive to the mining company deciding on new or continuing exploration activities.[2]

To examine the economic characteristics of exploration targets, a set of base case conditions is initially specified. The following expected

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1. Total revenue measures the size of a deposit in economic terms, and rate of return indicates the profitability of investing in its development. Net present value combines the size and profitability attributes of a deposit in a single measure.

2. Details of the methodology and data base may be found in Economic Effects of Smelter Controls on the Canadian Nonferrous Mining Industry, B.W. Mackenzie and M.L. Bilodeau, Technical Paper No. 2, (Kingston: Centre for Resource Studies, 1982).

long-term metal prices, in mid-1983 United States dollars, are used in this evaluation:

copper	1.15 per pound;
gold	550 per ounce;
lead	0.40 per pound;
molybdenum	6.00 per pound in concentrate;
silver	13 per ounce;
zinc	0.55 per pound;
exchange rate	0.80 U.S.$ per C$

Current (early 1983) federal corporate income tax, provincial corporate income tax, and provincial mining tax systems are applied. An individual project (stand-alone) basis of taxation is assumed. A 10-percent per year general rate of inflation is used to assess tax allowances and payments.

3. ECONOMIC CHARACTERISTICS OF EXPLORATION TARGETS

Number of Economic Discoveries

The base case conditions, specified in chapter 2, are initially applied to address the question: how many of the 275 historical discoveries would be economic if discovered today? These, then, will represent economic exploration targets under current outlook conditions. For this purpose, before-tax and after-tax discounted cash flow rates of return are assessed for each of the 275 discoveries. These rates of return are ordered from highest to lowest and plotted against the cumulative number of deposits. The resulting before-tax and after-tax schedules are presented in figure 1. The wide range of rates of return across the 275 base metal discoveries[3] reflects the high degree of variability in geological factors among the deposits.

If the cost of capital is imposed on these curves as the minimum acceptable rate of return, the number of economic deposits can be determined. For example, applying an 8-percent cost of capital as shown in figure 1, 122 of the discoveries would be economic on a before-tax basis, while 98 would remain economic after tax. Thus, taxation reduces the number of economically viable deposits from 122 to 98 (or, by 20 percent). This highlights an important inefficiency in existing Canadian taxation policies.[4]

The fact that only 98 (or 36 percent) of the 275 historical discoveries would be economic on an after-tax basis under today's outlook conditions is somewhat disturbing, because these are our 275 best base metal discoveries. The majority of these deposits have been successfully developed and operated in the past. This result indicates that current outlook cost, price, and taxation conditions are not as favourable as those which prevailed in the past.

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3. Only deposits with rates of return of at least -10 percent are shown in figure 1.

4. This inefficiency could be eliminated by a different taxation regime, such as a rate-of-return taxation system, which allows for the recovery of cost of capital as a minimum acceptable return on investment before tax liability is incurred. Only under these conditions would the number of economic deposits be identical before and after tax.

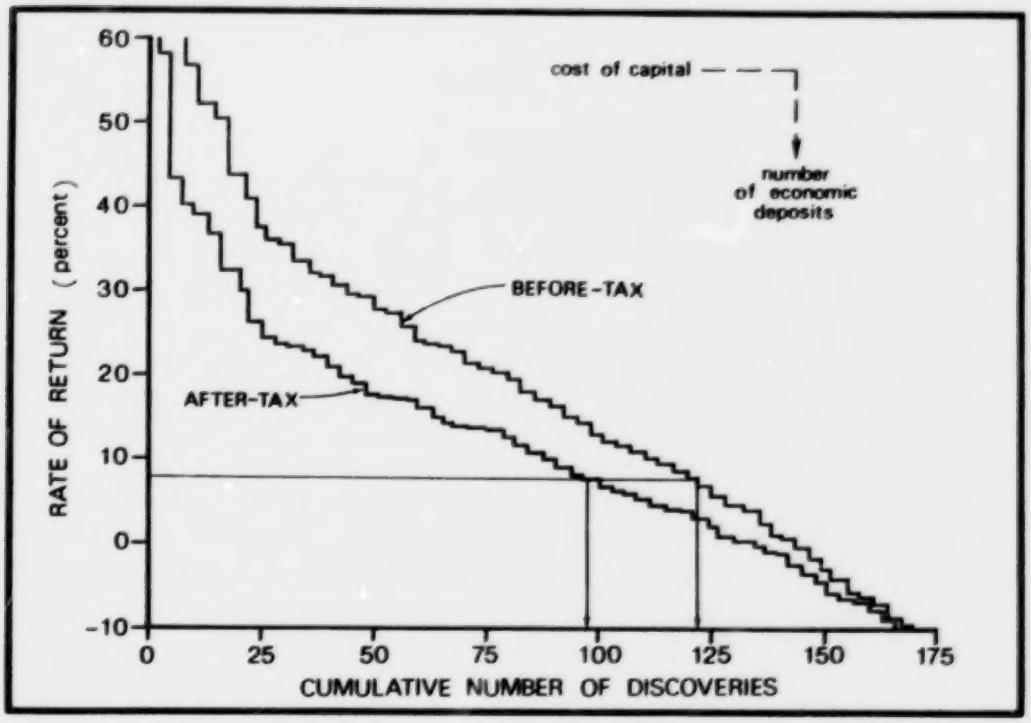

Figure 1. Relationship of Rate of Return to Cumulative Number of Deposits

The sensitivity of the number of economic discoveries, and therefore the number of economic exploration targets, to the minimum acceptable rate-of-return threshold should also be recognized. As shown in figure 2, a reduction in the cost-of-capital investment margin from 15 percent to 5 percent increases the number of economic discoveries from 67 to 116 (73 percent).[5] Thus, corporate and government policies which could result in modest reductions in financing costs would have a significant impact in stimulating mineral exploration and, thereby, the growth and prosperity of the Canadian mining industry.

5. Figure 2 is derived from figure 1.

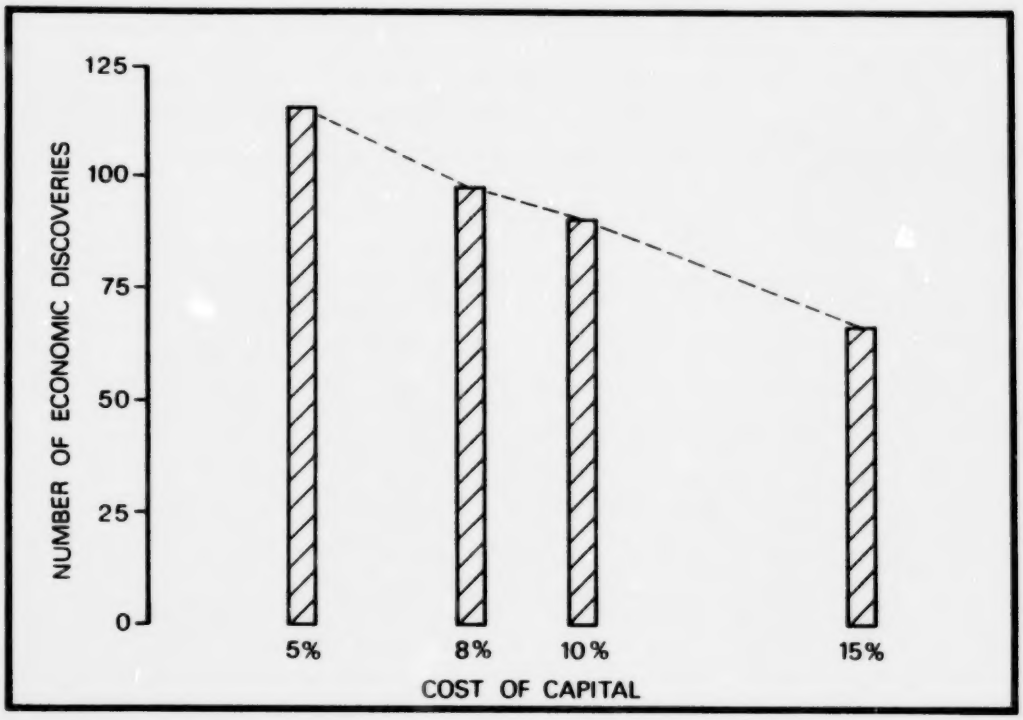

Figure 2. Number of Economic Deposits After Tax: Cost-of-Capital Variants

Value of Economic Discoveries

Assessment of the number of economic discoveries leads to the next issue: what would be the worth of these economic deposits as exploration targets today? To illustrate, the values of the 98 discoveries which, for base case conditions, are economic after tax are examined. The worth of an economic deposit is measured here by net present value, using the 8-percent cost of capital to discount the estimated time distribution of cash flows for each deposit back to an equivalent value at the start of the anticipated mine development.

After-tax net present values for the economic deposits[6] are ordered from highest to lowest and plotted against the cumulative number of economic discoveries. Results are shown in figure 3. Here we have an illustration of one of the fundamental risks of mineral exploration: the variability of returns given the discovery of an economic mineral deposit. This reflects the high degree of variability in tonnage, grade and other

6. Economic deposits are those with rates of return at least equal to the 8-percent cost of capital or, in other words, deposits with net present values at 8 percent equal to or greater than zero.

geological characteristics among economic deposits. To be realistic, both mining company planning and government mineral policy should recognize that there really is no such thing as a 'typical' deposit.

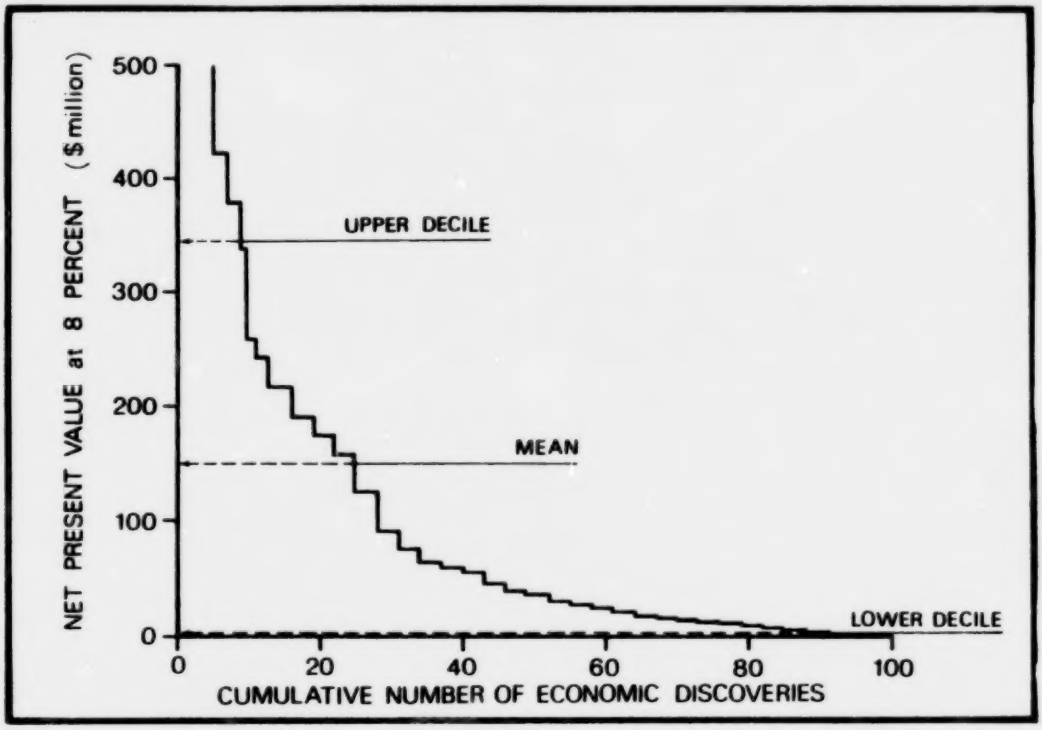

Figure 3. Relationship of Net Present Value to Cumulative Number of Economic Deposits

Key statistics from the net present value distribution shown in figure 3 are summarized in table 1. For the assumed base case conditions, the mean or average after-tax value of the 98 economic discoveries is $150 million. The variability of the return, given an economic discovery, is illustrated by the almost one-hundred-fold difference in value between the lower-decile and upper-decile economic deposits ($4 million and $346 million respectively).

Table 1

AFTER-TAX VALUE OF ECONOMIC DISCOVERIES: KEY STATISTICS

Key Statistic	Net Present Value at 8 Percent Start of Development ($ Million)
Upper decile	346
Upper quartile	156
Mean (average)	150
Median	40
Lower quartile	15
Lower decile	4

The value distribution is highly skewed. There are many low-value economic discoveries and relatively few of extremely high value. Thus, the mean value of the economic discoveries ($150 million) is quite close to the value of the upper-quartile deposit ($156 million), and almost four-times greater than the median or middle value of the distribution ($40 million). Given the discovery of an economic deposit, there is then almost a 75-percent chance that it will yield a lower than average return. On the other hand, there is more than a 25-percent chance that an economic discovery will yield a higher than average return. There is even a very small possibility of a 'billion dollar' discovery. Although this is an extremely rare outcome, the thought that any exploration program could lead to another Kidd Creek-type discovery is a great motivator in mineral exploration.

Figure 4 shows the average mix of metals in an economic base metal deposit, based on the 98 deposits which are economic after tax. Zinc accounts for 44 percent of the value of these deposits, copper 26 percent, lead 11 percent, silver 10 percent, gold 6 percent, and molybdenum 3 percent.[7] The polymetallic nature of these deposits provides a natural hedge against mineral market risks.

7. The amounts of metal recovered in concentrate are valued at the expected value prices specified in chapter 2.

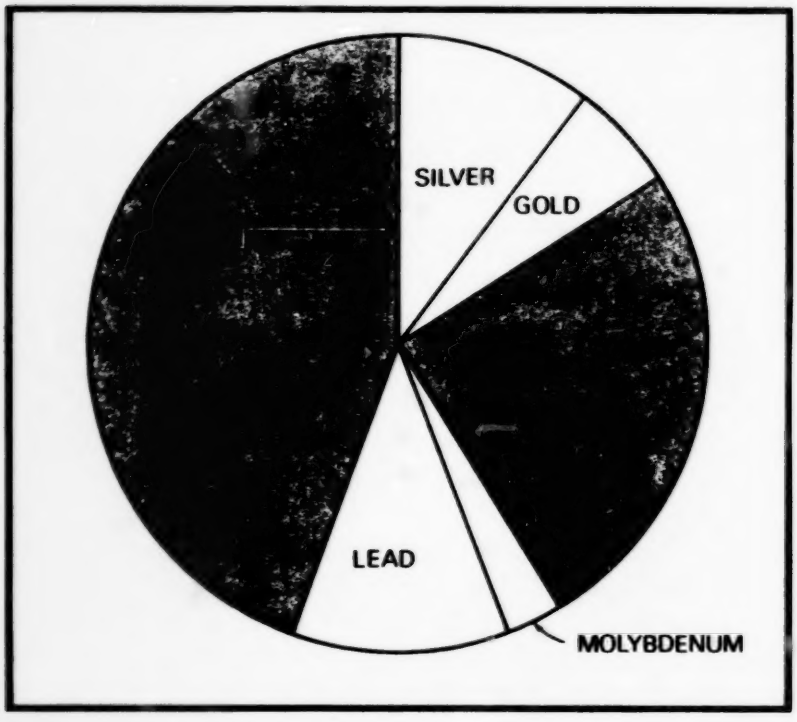

Figure 4. Average Metal Product Mix: After-Tax Economic Deposits

Metal Price Variants

Metal price is both the most important and the most uncertain variable determining the number and value of economic discoveries. This leads us to consider the question: how sensitive are economic mineral exploration targets to changing and uncertain metal prices? For this purpose, the expected or mean price outlook incorporated in the base case is bounded by upper- and lower-limit prices for each mineral commodity as specified in table 2. This provides a more realistic range of future price possibilities.

Two other sets of metal prices are also analyzed. One of these is the expected value prices projected in 1981 and used at that time to make similar assessments. The difference between the expected prices circa 1981 and present expectations illustrates the high level of uncertainty associated with long-term price forecasting, and the tendency to correlate long-term projections to current market prices. Thus, expectations in 1981 were much higher than those currently held.

Table 2

LONG-TERM METAL PRICE VARIANTS
(U.S. dollars)

Metal	Price Basis	1983 Long-Term Outlook			Expected Prices Circa 1981	January 1983 Spot Prices
		Lower Limit Prices	Expected Prices	Upper Limit Prices		
Copper	per pound metal	.95	1.15	1.40	1.32	.82
Gold	per ounce metal	400	550	800	792	504
Lead	per pound metal	.30	.40	.50	.55	.23
Molybdenum	per pound in con.	4.50	6.00	10.00	10.60	5.20
Silver	per ounce metal	10	13	20	22.40	13.30
Zinc	per pound metal	.45	.55	.65	.53	.42
Exchange Rate	U.S. $ per C$	.95	.80	.70	.85	.82

The second further set of metal prices considered are the January 1983 spot prices. These actual market prices are much lower than current price expectations. This reflects the high degree of cyclicity of short-term temporary base and precious metal price fluctuations which occur around the long-term more permanent price trends.

Figure 5 illustrates the sensitivity of the number of economic deposits after tax to these metal price variants. As prices are increased through the lower-limit to upper-limit range, the number of economic discoveries increases from 28 to 175. Using expected prices circa 1981, 144 of the 275 base metal discoveries would be economic, as compared to only 98 economic deposits based on current expectations. Applying the spot metal prices prevailing in January 1983, only 36 of the discoveries would be economic, a result close to that obtained using lower-limit prices.

The effect of these metal price variants on the average or mean after-tax value of an economic discovery is illustrated in figure 6. The average value associated with an economic discovery increases with metal prices, but the sensitivity is much lower than for the number of economic deposits.[8] The reason for this relative insensitivity is that higher returns for those deposits which remain economic as prices rise are largely offset by the low values of the more marginal deposits which become economic.

Time Trends

For current planning purposes, it is of interest to look within the overall historical experience to try to discern time trends in economic discovery rates and values. Two dynamic forces underlie mineral exploration: depletion, and advances in technology. The physical exhaustion of mineral deposits is inherent in their exploitation. Furthermore, exploration, guided by geological concepts and skills, is a systematic process in the long term, tending to detect first those deposits that are largest, highest grade, closest to surface, and closest to market. Consequently, the best deposits will, on average, be discovered, developed and exhausted first. Lower quality or smaller deposits remain for the future. Thus, depletion causes increasing costs and a deterioration in the economics of mineral exploration. However, the second offsetting

8. As prices are increased through the lower- to upper-limit range, the number of economic deposits rises by more than five times whereas the average return given the discovery of an economic deposit only increases by about 60 percent.

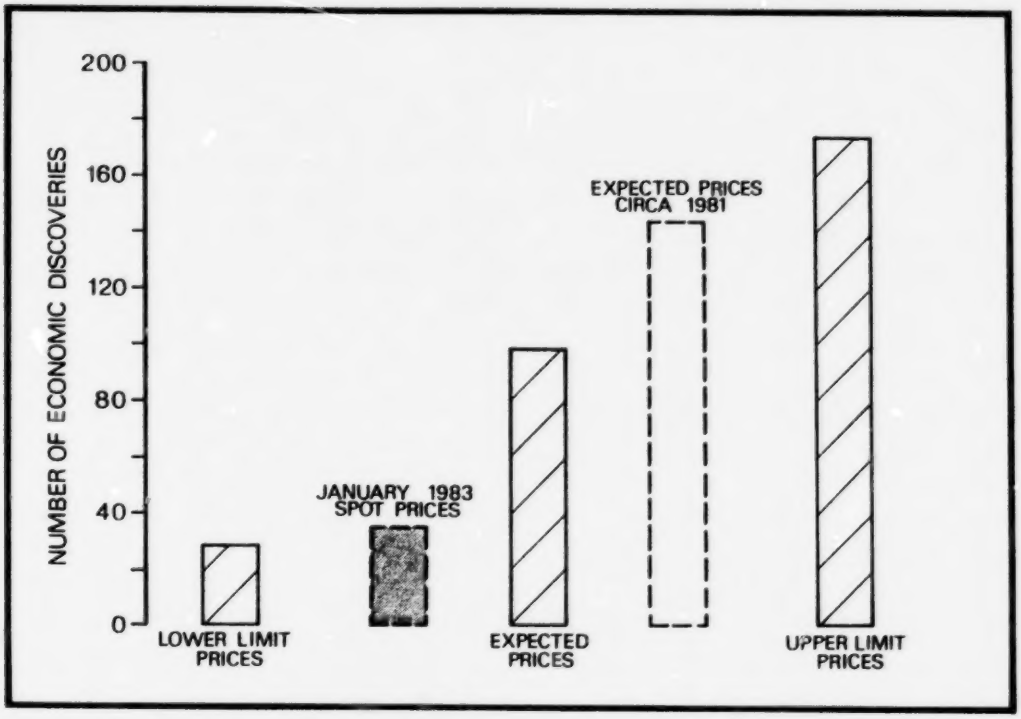

Figure 5. Number of Economic Deposits After Tax: Metal Price Variants

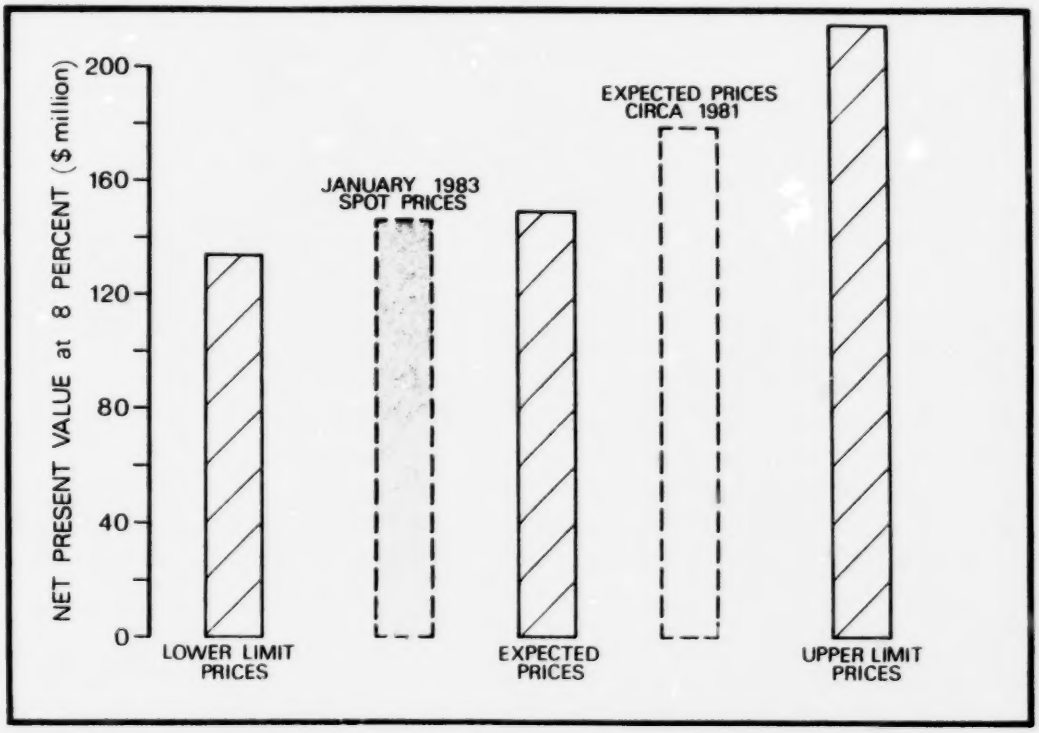

Figure 6. Average After-Tax Value of an Economic Discovery: Metal Price Variants

dynamic force is also at work - advances in technology. These advances may include more efficient and extensive exploration techniques, and improved mining and mineral processing methods. Advances in technology act to reduce costs and thereby improve the economics of mineral exploration. The resultant of these depletion and technological forces is an important determinant of whether exploration economics is in fact deteriorating or improving with time.

The interplay of depletion effects and advances in geological concepts and exploration technology is examined with respect to economic mineral exploration targets by analyzing time trends in the number and average value of economic discoveries. For this purpose the deposits are classified by discovery date as specified in appendix II. Thus, the 65 base metal discoveries made prior to 1946 are distinguished from the 210 deposits discovered during the thirty-two year period 1946-77. Then, the 1946-77 period is subdivided into two sixteen-year intervals and, finally, into four eight-year intervals.

The time trend in the number of economic discoveries is illustrated in figure 7. Of the 98 deposits evaluated as economic after tax, 16 were discovered prior to 1946 and 82 were discovered within the 1946-77 period.[9] Within the 1946-77 period, the economic discovery rate appears to have increased with time. This assessment does not consider, of course, the varying levels of exploration expenditure required to discover these economic deposits.

The time trend in the average value of these economic discoveries, expressed as a net present value at the start of development using an 8-percent discount rate, $150 million overall, is portrayed in figure 8. There is a sharp decrease in the average value from $248 million for the 16 economic discoveries made prior to 1946, to $130 million for the 82 economic deposits discovered during the 1946-77 period. This is due in part to the influence of the large and profitable Sullivan, Flin Flon, and Horne deposits on the pre-1946 results. It also no doubt reflects the benefits of advances in exploration technology, particularly airborne geophysics, in enabling the discovery of a relatively large number of small concealed massive sulphide deposits during the 1946-77 period.

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9. These economic discoveries represent 25 percent and 39 percent of the total number of deposits evaluated in the respective periods.

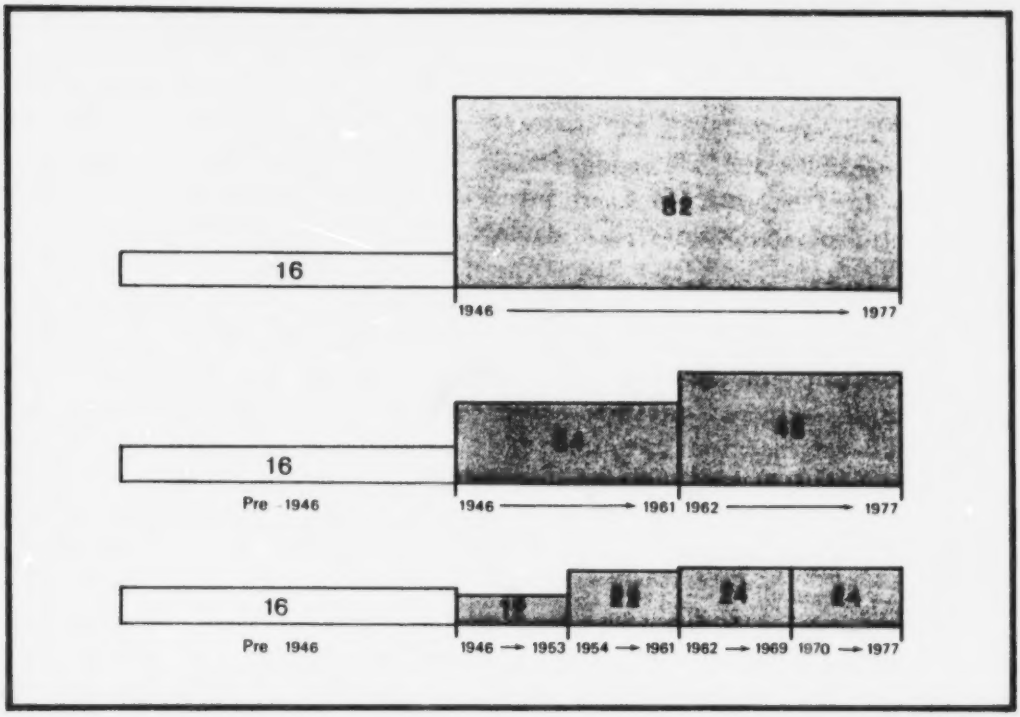

Figure 7. Time Trend in the Number of Economic Discoveries After Tax

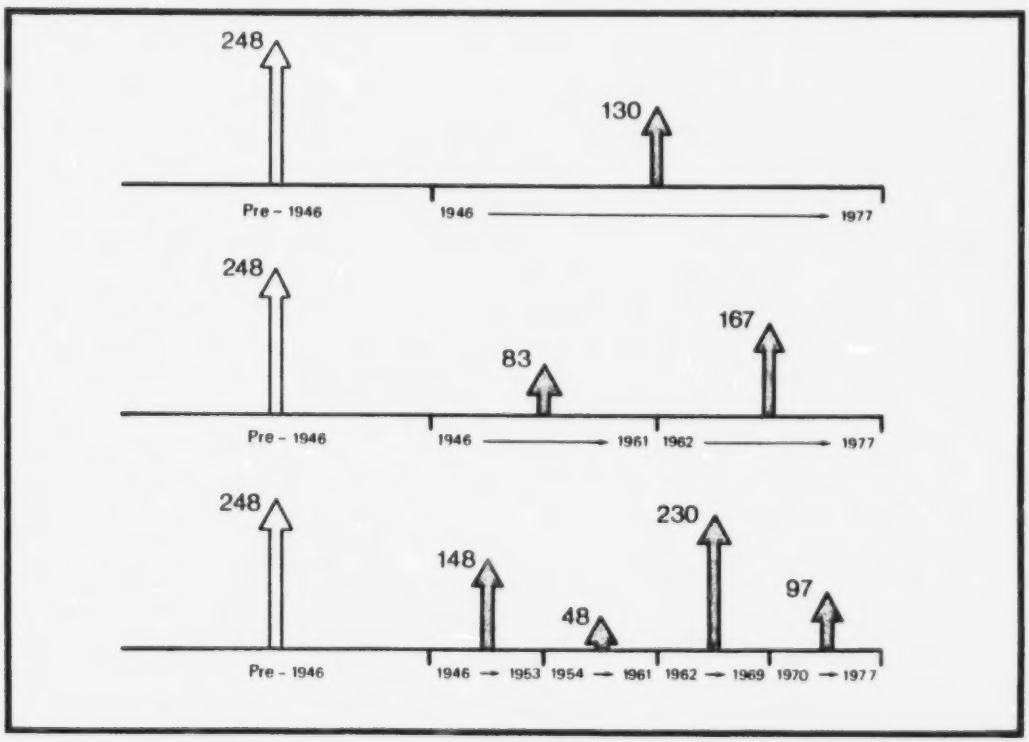

Figure 8. Time Trend in the Average After-Tax Value of an Economic Discovery

Within the 1946-77 period, the modern era of intensive and systematic base metal exploration in Canada, there is no discernible overall trend. The result for the 1962-69 time interval is heavily influenced by the singular value of the Kidd Creek discovery. With regard to the 1970-77 interval, past experience has shown an inherent bias in the data base to undervalue discoveries made most recently.

While the evidence in time trends is inconclusive and incomplete, it does not in general support the hypothesis that the economics of mineral exploration has deteriorated with time.[10]

Exploration Environments

Exploration planning is supported by various types of classification, for example, by exploration environment, geological setting and age, deposit type, or specific metals. These classification schemes are used to help formulate exploration programs designed to provide the most cost-effective path to the discovery of economic mineral deposits.

Here, we consider the characteristics of economic exploration targets classified by exploration environment. Exploration environments are primarily defined by geographical area and, then, by the geological settings and deposit types within these environments. Each exploration environment includes a number of specific geological settings that determine which deposit types are most likely to occur. Geological setting is defined in terms of tectonics, structure, stratigraphy, lithology, and of course age.

The three most important exploration environments in Canada are the appalachian, shield, and cordilleran regions.[11] The appalachian and

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10. A full analysis would have to consider trends in the exploration time and cost required to discover economic deposits, the effects of advances in mining and processing technology, and actual historical trends in market prices and the incidence of mining taxation.

11. The appalachian environment covers the island of Newfoundland, Nova Scotia, New Brunswick, and the province of Quebec south of the St. Lawrence River. This environment is mainly composed of rocks of paleozoic age, formed from 570 million years to 225 million

cordilleran environments are themselves coherent tectonic entities, whereas the shield environment includes a number of separate but interrelated tectonic units.

Of the 275 significant base metal deposits discovered in Canada to 1977, 39 are located in the appalachian environment, 139 in the shield, 88 in the cordilleran environment, the remaining 9 deposits being located elsewhere. The classification of these deposits by exploration environment is given in appendix I.

For base case conditions, the number of deposits evaluated as economic is: 14 (or 36 percent) of the deposits located in the appalachian environment, 46 (33 percent) of the shield deposits, and 30 (34 percent) of the deposits in the cordilleran environment.

The average after-tax value of an economic discovery within each of these exploration environments, expressed as a net present value at 8 percent evaluated at the start of development, is presented in figure 9. These values vary from $133 million in the shield and $151 million in the

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years ago in a tectonically active, geosynclinal belt. The appalachian environment is a notable source of both volcanogenic and sedimentogenic base metal deposits.

The shield environment occupies nearly half of Canada, forming the bedrock for most of Labrador, Quebec, and Ontario, the northern parts of Manitoba and Saskatchewan, and the central and eastern parts of the Northwest Territories. The shield consists of archean granite-greenstone areas separated and flanked by complex metamorphic zones and geosynclinal belts of proterozoic age. Thus, this environment is generally of precambrian age, formed more than 570 million years ago. However, the shield's archean province, of primary importance in terms of base metal endowment, consists of rocks more than 2,500 million years old. Volcanogenic deposits of copper and zinc, some containing gold, silver and lead, formed at this time. The shield contains most of Canada's nickel, copper-zinc, gold and iron ore deposits.

The cordilleran environment includes most of the province of British Columbia, the Yukon Territory, and small western segments of Alberta and the Northwest Territories. This environment is also a dominantly geosynclinal and tectonically active belt, composed of rocks of proterozoic, paleozoic, mesozoic and quaternary ages, formed between 2,500 million years and 65 million years ago. The cordilleran environment is an important source of porphyry, sedimentogenic, and volcanogenic base metal deposits.

appalachian environment, to $189 million in the cordilleran. It is interesting to note that these values are the resultant of much more variable average deposit size and grade characteristics among the environments. The average size of an economic deposit ranges from 16 million tonnes in the shield and 22 million tonnes in the appalachian environment, to 143 million tonnes in the cordilleran.[12] The average grade of an economic deposit, expressed in terms of net smelter return unit revenue at the minesite[13], varies from $54 per tonne in the cordilleran, to $106 per tonne in the shield and $120 per tonne in the appalachian environment. Thus, the average deposit size and grade combinations for the exploration environments tend to have a cancelling-out effect in terms of the variability of the average value of an economic deposit.

The average metal product mix for economic deposits within each environment is illustrated in figure 10. In all cases, zinc is the most important commodity produced; its share of revenue varies from 37 percent in the shield to 55 percent in the cordilleran environment. Copper is second in importance in the shield and cordilleran environments, accounting for 36 percent and 25 percent of revenue respectively. Lead contributes 17 percent of revenue in the appalachian environment and 15 percent in the cordilleran. Precious metals account for 27 percent of revenue in the shield, 22 percent in the appalachian environment, and 9 percent in the cordilleran.

Deposit Types

While exploration environments provide a useful geographical focus for the allocation of exploration resources, parameters such as geological setting and age, deposit types, specific metals, and models built on these parameters, are more important in focusing exploration. From the point of view of this study, economic exploration targets are classified into the three main base metal deposit types: volcanogenic, sedimento-

12. Deposit size is measured here by the recoverable ore reserve tonnage.

13. This unit revenue is assessed by valuing recoverable ore reserve grades at expected value prices, and then making deductions for mineral processing losses, smelting and refining charges, and concentrate transportation costs.

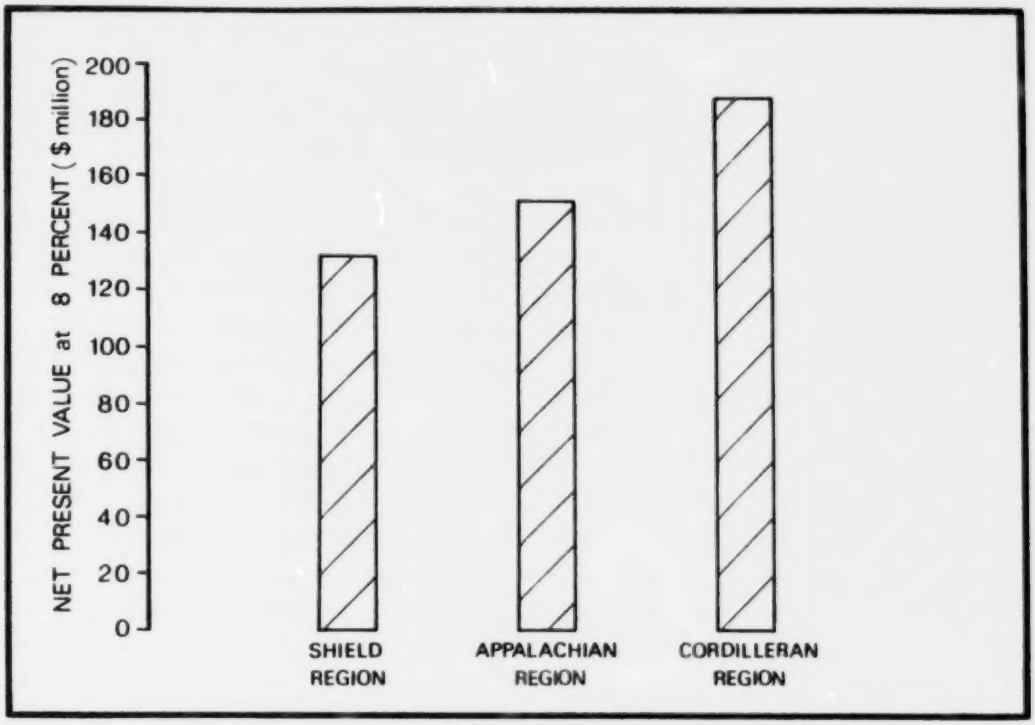

Figure 9. Average After-Tax Value of an Economic Discovery by Exploration Environment

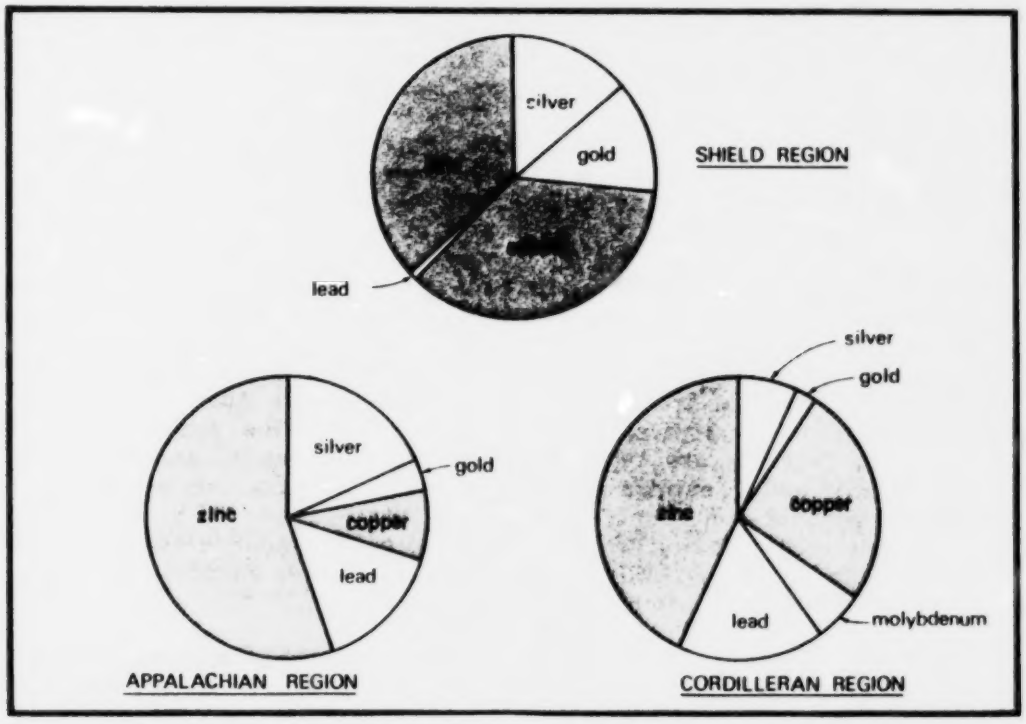

Figure 10. Average Metal Product Mix by Exploration Environment

genic, and porphyry deposits.[14] These deposit types reflect specific geological settings within the overall exploration environments.

The base metal deposit data base comprises 152 volcanogenic deposits, 37 sedimentogenic deposits, 30 porphyry deposits, and 56 other types of deposit.[15] For base case conditions, the following numbers of deposits are assessed as being economic: 54 (or 36 percent) of the volcanogenic deposits, 19 (51 percent) of the sedimentogenic deposits, and 11 (37 percent) of the porphyry deposits.

The average after-tax value of an economic deposit for each of these deposit types is shown in figure 11. As in the case of the regional variants, results are remarkably similar, considering the quite different size and grade characteristics which typify the individual deposit types. The average size of an economic deposit ranges from 21 million tonnes for a volcanogenic deposit to 298 million tonnes for a porphyry deposit. Aver-

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14. Volcanogenic massive sulphide deposits are defined by three major characteristics: occurrence of mineralization in a stratiform zone of massive sulphides; association of deposits with extrusive submarine volcanic rocks; and deposition of the ore from the discharge waters of submarine hot springs. Volcanogenic deposits are typically small and high grade. Occurring in active tectonic zones at intervals through the entire geological time frame, volcanogenic deposits are found in the shield, appalachian, and cordilleran environments.

    Sedimentogenic base metal sulphide deposits are defined on the basis of their association with sedimentary host rocks, typically shale or carbonate marine sediments. Sedimentogenic zinc-lead deposits, which may contain copper and silver, are usually of medium size and grade, occurring in sediments formed since about 2,000 million years ago. This deposit type is mainly found in the appalachian and cordilleran environments.

    Porphyry deposits are invariably related, both spatially and genetically, to highly fractured and hydrothermally altered zones in complex high level felsic intrusions within active tectonic belts. Porphyry deposits are typically large and low grade, and may contain copper only, copper-gold, copper-molybdenum, or molybdenum with or without tungsten. This deposit type tends to be identified with relatively young rocks, especially mesozoic-tertiary active zones such as the cordilleran environment. Sub-economic examples of this type are known in the precambrian.

15. The other deposit types include chibougamau-type, skarn, red bed copper, breccia pipe, native copper in basalt, and copper and molybdenum vein-type deposits. Lead-zinc-silver vein deposits are excluded from the data base.

age deposit grade, measured by net smelter return unit revenue at the minesite, varies from $21 per tonne for the economic porphyry deposits to $117 per tonne for the volcanogenic deposits. Average values for the sedimentogenic deposits fall between these extremes: average deposit size is 47 million tonnes, and average unit revenue is $65 per tonne.[16] As illustrated in figure 11, the economic consequences of these wide variations in geological characteristics are much less pronounced due to the cancelling-out of size and grade effects among the deposit types. The average after-tax value of an economic deposit varies from $139 million for the sedimentogenic deposits, to $163 million for the porphyry deposits, and $181 million for the volcanogenic deposits.

The average metal product mix for each deposit type is examined in figure 12. Volcanogenic deposits provide the most diversifed spread of metals. Zinc is the most important commodity produced from the sedimentogenic and volcanogenic deposits, accounting for 74 percent and 44 percent of revenue respectively. Copper contributes 70 percent of revenue from porphyry deposits and 23 percent of revenue from volcanogenic deposits. Lead and molybdenum account for about one-fifth of the revenue from sedimentogenic and porphyry deposits respectively. Precious metals contribute 24 percent of the revenue from volcanogenic deposits, 11 percent from porphyry deposits, and only 4 percent from sedimentogenic deposits.

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16. Note that the average deposit size and grade characteristics are more distinct for the deposit types than for the exploration environments which contain a mixture of deposit types.

    A comprehensive statistical analysis of the size, grade and value characteristics of base metal deposits in Canada, appraised by deposit type, is being prepared for publication by the Centre for Resource Studies.

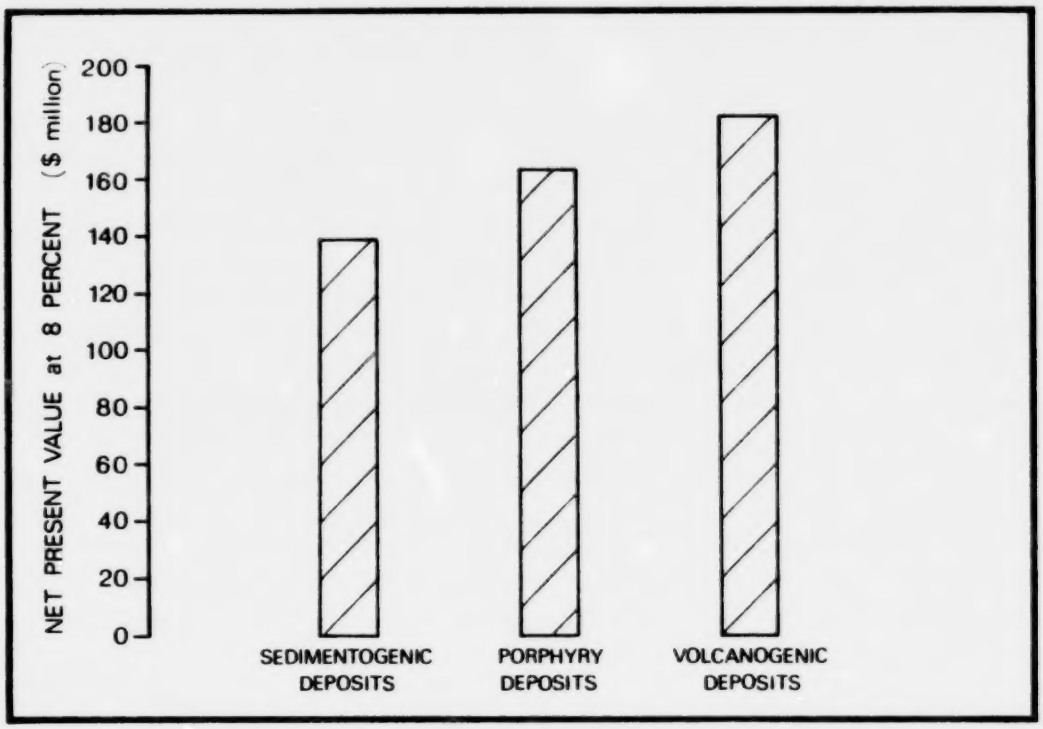

Figure 11. Average After-Tax Value of an Economic Discovery: Deposit Type Variants

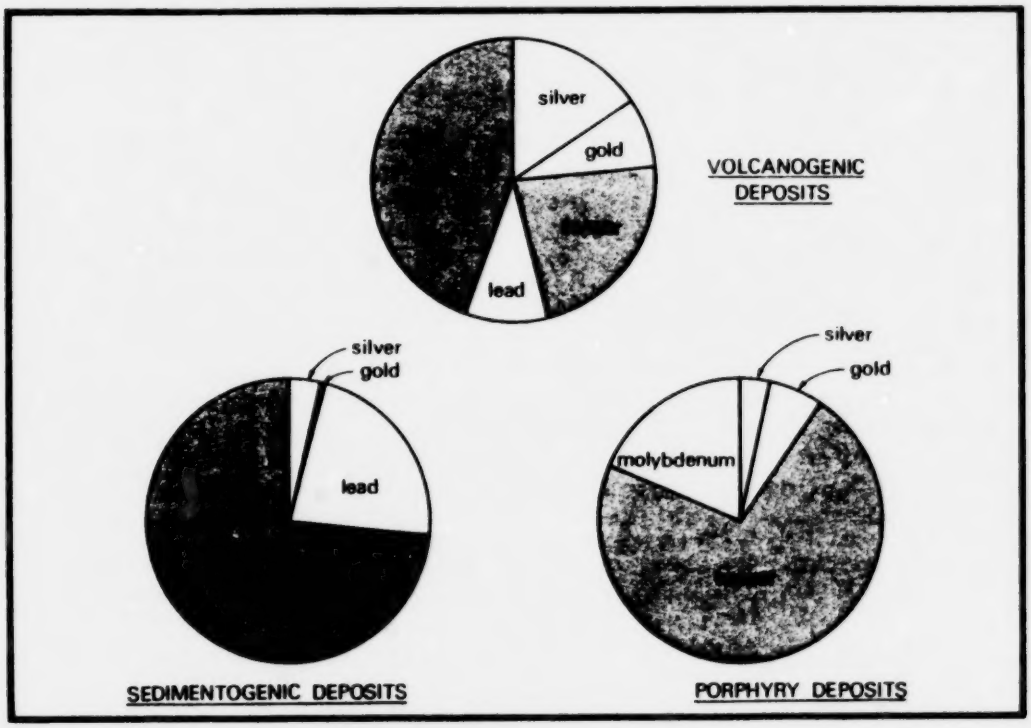

Figure 12. Average Metal Product Mix: Deposit Type Variants

4. EFFECT OF INDIVIDUAL METALS ON THE ECONOMICS OF PROSPECTIVE EXPLORATION TARGETS

Base metal deposits are typically polymetallic, as illustrated by the pie diagrams in chapter 3. The different economic attributes of the individual metals contained are examined here. For this purpose, hypothetical single-metal deposits of zinc, copper, and gold are considered as prospective exploration targets.

The evaluation is based on the expected metal prices specified in chapter 2. General net smelter conditions for zinc and copper concentrate, and typical marketing arrangements for gold, are used to work the projected metal prices back to revenue estimates for the sale of concentrate and impure gold bullion. Generalized costing relationships, reflecting an order-of-magnitude level of accuracy, are applied to estimate mill recovery factors, concentrate transportation costs, mine and mill capacities, preproduction capital costs, sustaining capital requirements, and operating costs.

An underground mining operation, located in Ontario, with the following specifications, is assumed:

- 300-metre shaft depth;
- 10-metre average deposit width;
- blasthole open stoping mining method;
- 80-percent mine recovery factor;
- 10-percent mine dilution factor;
- 2-year preproduction development period.

Base case taxation conditions, as specified in chapter 2, are applied.

The hypothetical deposits are each assumed to have a geological ore reserve of 2,500,000 tonnes and a gross in-situ deposit value of $500 million (or $200 per tonne).[17] Applying the expected metal prices, geological deposit grades are as follows:

zinc deposit	13.2 percent;
copper deposit	6.31 percent;
gold deposit	9.05 grams per tonne.

17. Gross in-situ value is the product of geological reserves, geological grades, and metal prices.

With respect to infrastructure requirements, the deposits are assumed to be located within 20 kilometres of an existing road and a power line. New townsite, housing and milling facilities have to be constructed. Zinc and copper concentrates are shipped by road and rail to domestic smelters.

Evaluation results for the three hypothetical deposits are presented in table 3.

Table 3

HYPOTHETICAL ZINC, COPPER AND GOLD EXPLORATION TARGETS
($ million)

	Zinc Deposit	Copper Deposit	Gold Deposit
Gross in-situ value	500	500	500
Less: Mining and milling losses Smelting and refining charges Product transportation costs	339	238	131
Revenue at the minesite	161	262	369
Less: Capital expenditures Operating costs	186	167	159
Before-tax cash flow	-25	95	210
Less: Taxation payments	1	55	123
After-tax cash flow	-26	40	87
Net present value at 8 percent, start of development	-33	10	38
Rate of return	-8	13	25

While each mineral deposit and mine has its own special geological and economic characteristics, the hypothetical cases evaluated in table 3 represent typical conditions for each of the three metals. Thus, the zinc deposit requires somewhat more costly processing facilities and achieves lower milling recoveries than the copper mine. More importantly, smelting and refining charges for zinc concentrate are much more severe than in the case of copper. Comparing the hypothetical copper and gold deposit results, the main difference is the smelting and refining charges for copper concentrate which are much higher than marketing costs for the impure bullion product of the gold mine. The higher costs

of developing and operating the zinc deposit compared to the copper deposit, and of the copper deposit relative to the gold deposit, are only partially compensated for by lower taxation payments, and by a lower cost of capital in dollar terms.[18]

The hypothetical examples show that the three metals - zinc, copper, and gold - have quite different abilities to convert in-ground values into actual economic returns. Although the gross in-situ value is the same in each case, the zinc deposit is quite uneconomic, the copper deposit is marginally economic, and the gold deposit is very profitable. Other things being equal, then, gold deposits represent more attractive exploration targets then copper deposits, and copper deposits represent more attractive exploration targets than zinc deposits. The same reasoning holds to a lesser degree with respect to the relative mix of metals in polymetallic base metal deposits; i.e. gold content is economically preferable to copper content, and copper content is preferable to zinc content, given the same overall gross in-situ value.

In the next chaper, these hypothetical deposit results are generalized for the assessment of minimum acceptable tonnage-grade conditions.

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18. The 8-percent cost of capital in dollar terms is the difference between the undiscounted after-tax cash flow and the net present value at the start of development.

5. MINIMUM ACCEPTABLE EXPLORATION TARGET CONDITIONS

A question which should be asked before undertaking exploration is - what size and grade of deposit will have to be discovered to constitute an economic find? Then, given present knowledge of the contemplated exploration environment and the characteristics of past discoveries, a judgement can be made concerning the likelihood of in fact finding such a deposit. This helps to determine whether exploration is economically worthwhile. The establishment of minimum acceptable exploration target conditions also assists in screening exploration prospects if and when exploration proceeds.

To illustrate the application of minimum acceptable target conditions for exploration planning purposes, generalizations are made from the 2,500,000-tonne deposit examples evaluated in chapter 4. A minimum acceptable economic discovery is defined here by an 8-percent rate of return or, in other words, by a zero net present value at the start of development using an 8-percent cost of capital discount rate. The required size is measured by the geological tonnage of the deposit. The required grade is measured by the geological grade of the deposit.[19] Thus, minimum exploration target conditions are assessed as a function of both tonnage and grade. The required conditions may then be evaluated for appropriate commodity type, price, processing and remoteness variants.

Minimum acceptable target conditions for zinc, copper and gold deposits are compared in figure 13. These assessments are based on expected value prices, and make provision for new processing, townsite, and housing facilities. Generalized marketing conditions and costing relationships are once again applied. Targets with tonnage-grade conditions which lie above the respective curves represent economic deposits, while those which fall below would be uneconomic. Tonnage-grade combinations on each curve represent possible breakeven conditions, i.e. an 8-percent rate of return.

The horizontal geological grade scales for the individual metals are standardized in terms of gross in-situ value per tonne. Thus, figure 13 shows that, for any set of tonnage-grade conditions, a gold deposit

19. For polymetallic deposits, either an equivalent metal grade or gross in-situ value per tonne would have to be used to indicate the required deposit grade. In either case, assumptions concerning metal prices are included in the grade parameter.

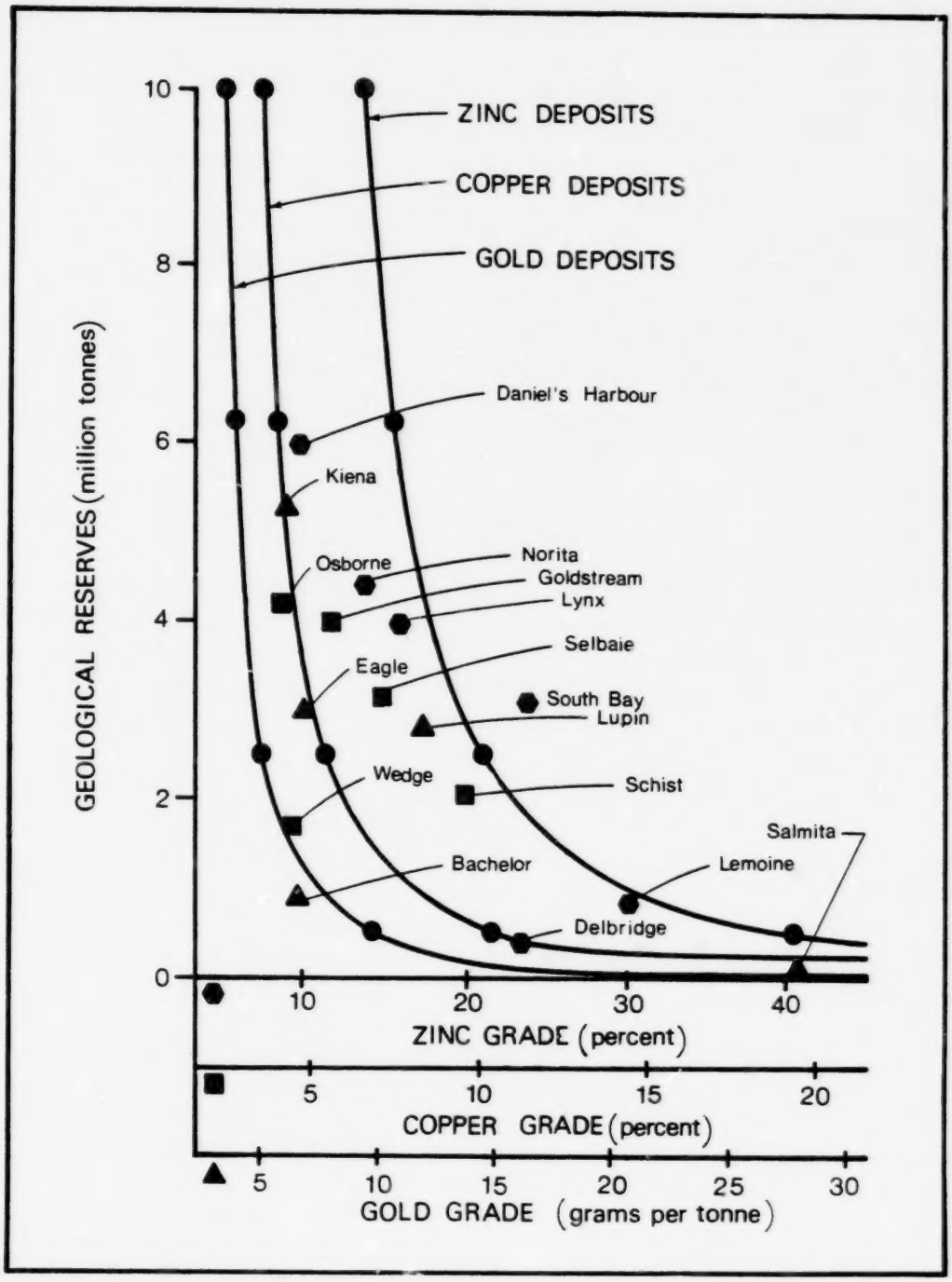

Figure 13. Minimum Acceptable Exploration Target Conditions for Zinc, Copper and Gold Deposits

represents a more attractive exploration target than a copper deposit, and a copper deposit is a more economic target than a zinc deposit. These results reflect the different costs associated with converting the three metals from in-situ values into refined products as described in chapter 4. Generally, the area between the curves represents tonnage-grade combinations for which exploration targets containing the more economically attractive metal (bottom curve) would be economic but for which targets containing the less attractive metal (top curve) would be uneconomic. Other factors being equal, expectations of larger tonnages and higher grades are required to justify exploration for zinc deposits than for copper deposits, and for copper deposits than for gold deposits.[20]

Tonnage-grade points have also been plotted on figure 13 for selected actual precious and base metal deposits. These are intended to provide background perspective for the minimum target condition curves. However, it is important to realize that the actual deposit tonnages and grades generally represent incomplete estimates.[21] Also, the actual deposits have a wide range of revenue and cost characteristics which differ from the specifications and generalized relationships that have been assumed in assessing the minimum target curves. Thus, the results cannot be used to indicate whether the actual deposits have been, are, or will be economic. Rather, these results can only be applied to answer more hypothetical questions. For example, would the estimated tonnage and grade of an actual deposit represent an economic exploration target given the particular conditions assumed in evaluating the minimum target conditions?

Minimum acceptable exploration target conditions for gold deposits have been evaluated as a function of gold price. Results are presented in figure 14. As the projected gold price rises through the range of lower-limit to upper-limit values, minimum economic conditions are extended to lower tonnages and grades. This improvement appears to be subject to diminishing returns. There is a greater shift in the minimum acceptable boundary from $400 to $550 per ounce than from $550 to $800 per

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20. Although the differences would be smaller, the same reasoning would apply to the relative proportions of metals in polymetallic deposits.

21. For example, there have been large increases in the tonnage estimates for the Hemlo gold properties between March 1983, when this paper was presented and October 1983, when it was being prepared for publication.

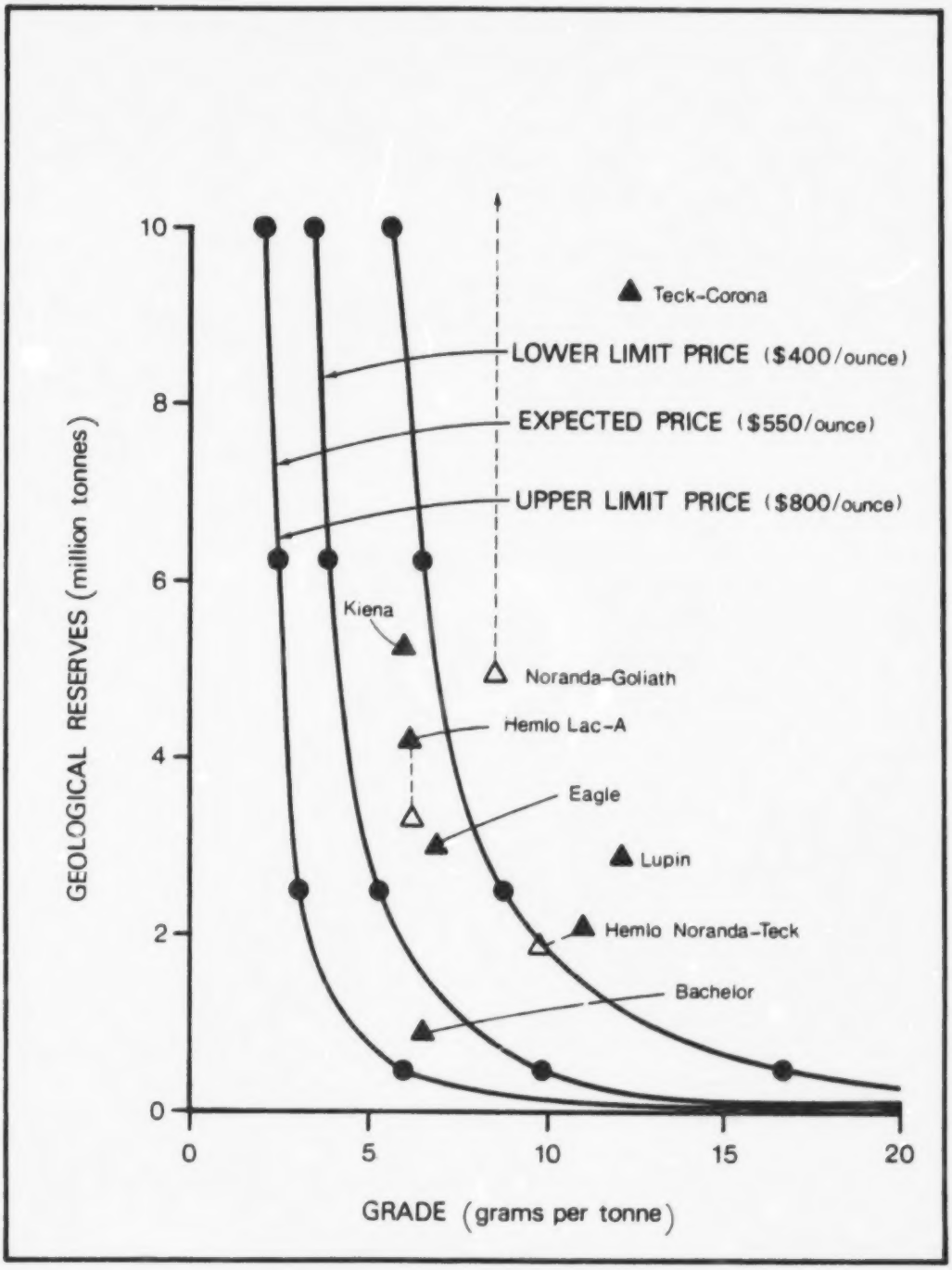

Figure 14. Minimum Acceptable Gold Exploration Target Conditions: Price Variants

ounce. In any case, the high degree of uncertainty associated with the prediction of future gold price levels has a critical bearing on the number and value of economic gold exploration targets.

Finally, minimum tonnage-grade conditions are presented in figure 15 for gold exploration targets as a function of remoteness. Three remoteness variants are considered:

- a location with existing townsite and milling facilities;
- a location requiring the construction of new housing, townsite and milling facilities;
- a location sufficiently remote to require a fly-in program.

Minimum economic target conditions become increasingly severe as remoteness is increased. This does not mean that exploration in remote areas is necessarily uneconomic. Rather, the results indicate that expectations of higher tonnages, grades and prices are required to economically justify exploration there. Figure 15 also illustrates the importance of infrastructure to the economic viability of exploration targets.

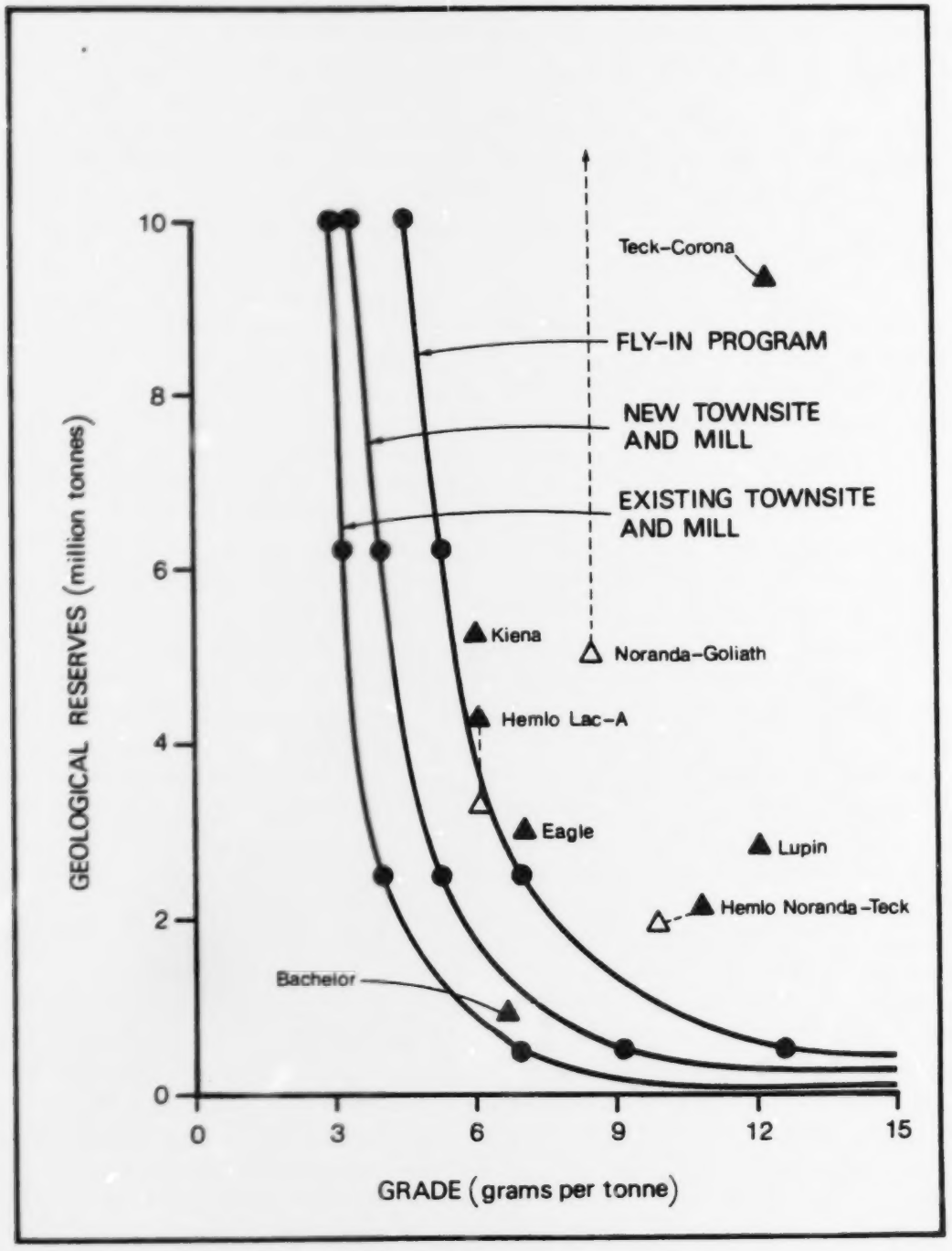

Figure 15. Minimum Acceptable Gold Exploration Target Conditions: Remoteness Variants

6. ECONOMIC JUSTIFICATION FOR EXPLORATION

Having examined the characteristics of economic exploration targets, this final chapter turns attention to the more fundamental issue: is exploration for these targets economically worthwhile? This question is addressed by considering the relationship between the value of economic targets, and the exploration time and cost required to realize that value. For this type of overall evaluation, the complete mining cycle, including exploration, development, and production, is viewed from the start of exploration.

The case of base metal exploration in Canada is used for illustration, but the evaluation is restricted to the 1946-77 period because exploration expenditure data are not available prior to 1946. The economic justification for mineral exploration is analyzed in two ways. First of all, the expected value of mineral exploration is assessed. Then, the breakeven costs and commodity prices required to justify exploration are determined.

The Case of Base Metal Exploration in Canada

The starting point for analyzing the economic justification for exploration is an evaluation of the time distribution of average cash flows associated with the discovery of an economic deposit. The individual discoveries are evaluated as described in chapter 2. The required cash flow distribution for the development and production phases is then derived by averaging the cash flow estimates for all deposits evaluated as being economic. These average or expected results for the development and production phases of the mining cycle are then combined with estimates made for the exploration phase. With respect to the exploration phase, total exploration expenditures are divided by the number of economic discoveries evaluated to determine the average exploration expenditure associated with an economic discovery. This average exploration expenditure per economic discovery is then divided by an estimated efficient annual exploration budget rate to evaluate the average exploration time required to find and delineate an economic deposit.

The end result of this evaluation process is the assessment of a time distribution of average cash flows for an economic discovery over the exploration, development and production phases of the mining cycle. This cash flow distribution is then applied to examine the economic justification of exploration.

In the case of base metal exploration in Canada during the period 1946-77, 210 significant base metal deposits were discovered, as specified in appendix I. This result is estimated to have required an exploration expenditure of approximately $3,534 million, including both successful and unsuccessful programs and projects. A $3.0 million annual budget is assumed for an exploration organization.[22]

Initially, the economic justification for exploration is assessed on a potential value or before-tax basis. Next, existing Canadian federal and provincial taxation regimes are imposed to evaluate exploration, from the investor's viewpoint, on an after-tax basis. A mixture of large company and small company tax conditions is assumed. Hence, exploration costs are expensed for tax purposes, and the development and production phases are taxed on an individual project basis. This is consistent with the tax treatment used in the examples presented in previous chapters.

Expected Value of Mineral Exploration

The economic justification for base metal exploration in Canada is assessed here by the expected value of exploration. Expected value is the average value that exploration will yield in the long term, when the successes and failures associated with a very large (theoretically infinite) number of discoveries are considered. The expected value of exploration per economic discovery (EV) is the average return or value associated with the discovery of an economic mineral deposit (R), minus the average exploration cost required to find and delineate an economic deposit (E). Thus:

$$EV = R - E.$$

For potential value or before-tax conditions, 101 of the 210 base metal deposits discovered during the 1946-77 period are found to be economic. The cost and revenue characteristics of these 101 deposits are used to assess the time distribution of average cash flows for an economic deposit. This distribution is shown in the top panel of figure 16 and summarized as follows.

Exploration: average expenditure per economic discovery of approximately $35 million, invested at the assumed annual budget rate of $3 million over a period of about 11.7 years.

22. All values are once again expressed in constant mid-1983 dollars.

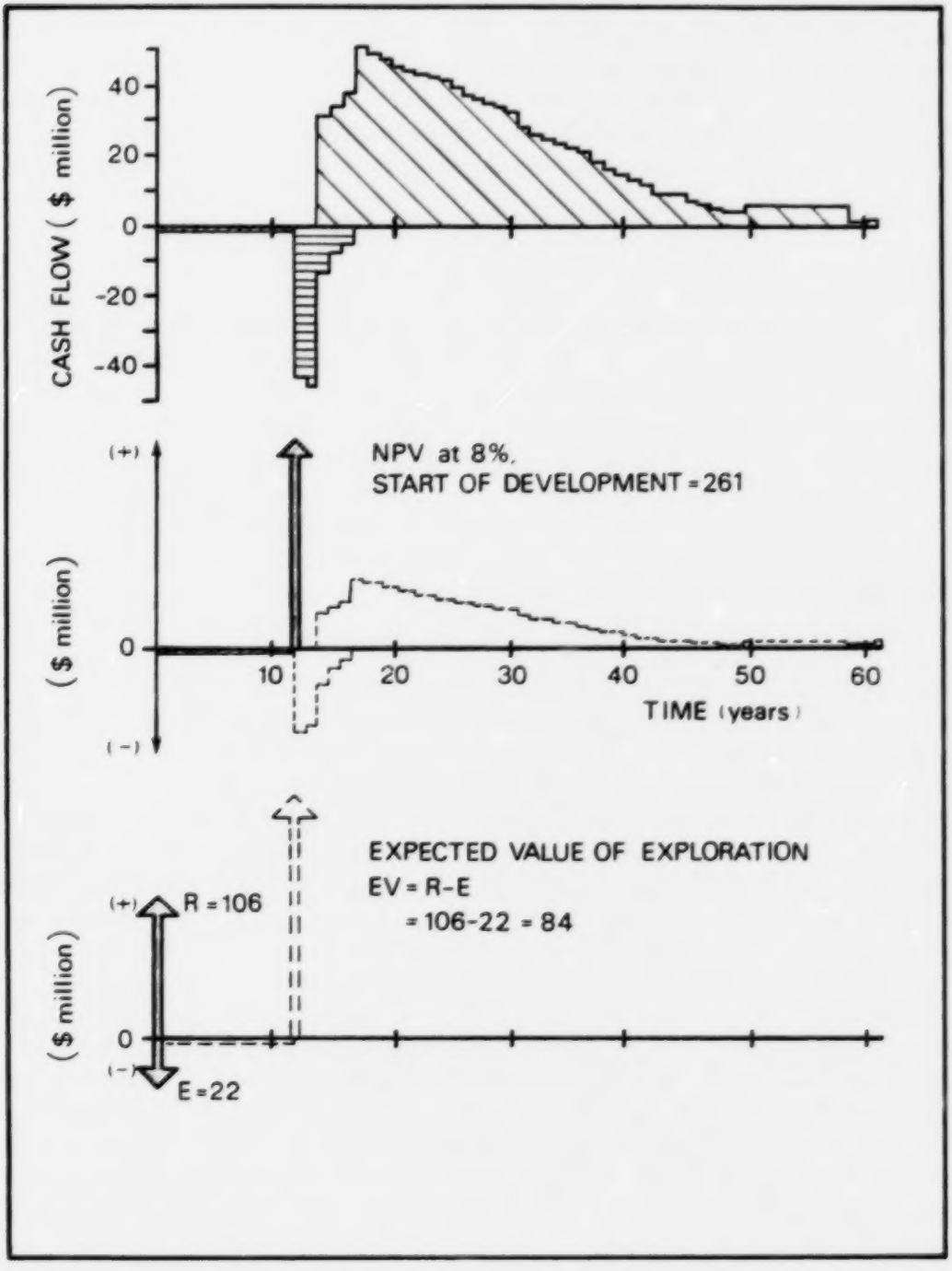

Figure 16. Before-Tax Expected Value of Exploration

Development: up to five years, with average capital costs of $117 million.

Production: up to 48 years, with cash flows which vary as shown in the top panel of figure 16. Average revenues total $1,781 million and average production costs are $744 million.

For the purpose of assessing the expected value of exploration per economic discovery (EV), the development and production phase cash flows, totalling $920 million, are initially discounted back to an equivalent value at the start of development using the 8-percent cost of capital. The resulting net present value at the start of development, $261 million, is shown in the middle panel of figure 16. To compare this average return from the discovery of an economic deposit with the associated exploration costs, the estimated values are then discounted back to the start of exploration. As illustrated in the bottom panel of figure 16, the average return of $106 million evaluated at the start of exploration can then be compared with the discounted exploration expenditure of $22 million. Thus, the economic justification for mineral exploration is measured by the following expected value per economic discovery.

$$EV = R - E = 106 - 22 = \$84 \text{ million}$$

This means that, on average, based on the assumed conditions, $84 million of new wealth or economic surplus is associated with the discovery of an economic base metal deposit. Alternatively, the expected value of base metal exploration may be expressed as a 16.3-percent discounted cash flow rate of return.[23] In any case, these results demonstrate the economic justification for base metal exploration. They indicate that base metal mineral endowment in Canada is of a high quality and has the potential to increase substantially the net value or wealth available to Canadian society.

On an after-tax basis, the number of economic deposits is reduced from 101 to 82. Nineteen deposits which represent potentially economic exploration targets are rendered uneconomic by current tax policies. The after-tax time distribution of average cash flows for an economic deposit is shown in the top panel of figure 17 and summarized as follows.

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23. Rate of return is defined as the discount rate which produces a zero net present value. The 16.3-percent rate of return has been determined from the cash flow distribution shown in the top panel of figure 16. Here, the economic justification of exploration is represented by the difference between this rate of return result and the 8-percent cost of capital.

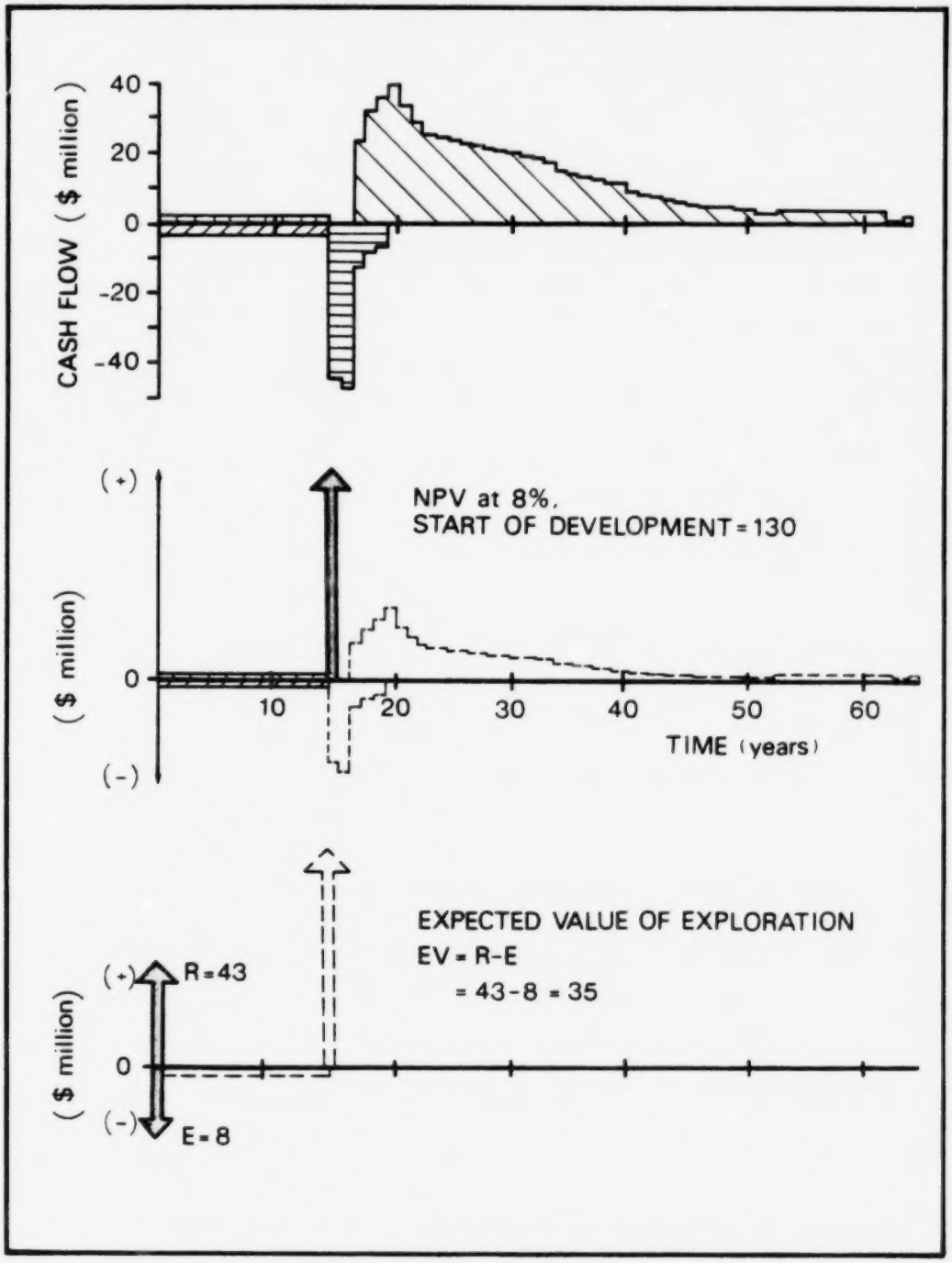

Figure 17. After-Tax Expected Value of Exploration

Exploration: average expenditure per economic discovery of $43 million over about 14.4 years, offset by exploration tax credits of approximately $29 million, resulting in an after-tax cost of $14 million.

Development: up to five years, with average capital costs of $122 million.

Production: up to forty-eight years, with cash flows which vary as depicted in the top panel of figure 17. Average revenues total $2,036 million, production costs are $810 million, and federal and provincial tax payments total $612 million.

Development and production phase cash flows, totalling $492 million, discount back at 8 percent to a net present value at the start of development of $130 million (middle panel, figure 17), and then to a net present value at the start of exploration of $43 million (bottom panel). This $43 million average after-tax return from the discovery of an economic deposit can then be compared with the discounted after-tax exploration expenditure of about $8 million. Thus, the after-tax expected value of base metal exploration per economic discovery is evaluated as follows.

$$EV = R - E = 43 - 8 = \$35 \text{ million}$$

This means that, on average, an after-tax profit of $25 million is realized from an $8-million after-tax exploration investment. The economic justification for exploration in terms of investment incentive is also reflected by a 14.9-percent after-tax discounted cash flow rate of return, as compared to the 16.3-percent potential rate of return and the 8-percent cost of capital. These results suggest that the investment incentive provided for base metal exploration in Canada under current taxation policies, assuming expected value prices, and considering the risks involved, is not unattractive overall.

Breakeven Costs and Prices

The economic justification for exploration can also be analyzed on the basis of breakeven costs and prices. For this purpose, costs are expressed per unit of metal product. This approach is useful because of the high degree of uncertainty inherent in metal price forecasts. Rather than assume a particular price level, the evaluation is carried out as a function of price. Then, a breakeven point is determined where the sum

of all costs - exploration, development, and production costs, and the cost of capital - just equals the metal price. Using this approach, the economic justification of exploration is then based on a judgment as to whether the future metal price is likely to be greater or less than the critical breakeven price determined.

The starting point for the breakeven cost and price analysis is, once again, the estimation of the time distribution of average cash flows associated with an economic discovery. For example, in the case of expected metal prices, the before-tax and after-tax cash flow distributions portrayed in the top panels of figures 16 and 17, respectively, are utilized. However, for purposes of determining the breakeven point, where costs just equal price, estimates are required as a function of price. For each price level, average total costs from the cash flow distribution are expressed as equivalent costs per unit of metal product recovered from economic deposits. The sum of these costs is then compared with the assumed metal price. This provides the basis for determining the critical breakeven price.

In the case of base metal exploration in Canada during the period 1946-77, equivalent costs per pound of metal recovered from economic deposits are assessed for lower-limit, expected value, and upper-limit price levels. Due to the polymetallic nature of base metal deposits, results are expressed in terms of U.S. cents per pound of copper equivalent. The long-term metal prices specified in table 2 are used for this purpose.[24]

Before-tax breakeven cost results are presented in figure 18. At expected value prices, breakeven costs total 87 U.S. cents per pound of copper equivalent in relation to the projected copper price of 115 U.S. cents per pound. The economic justification of exploration is measured here by the net return or economic surplus of 28 U.S. cents per pound. This result is comparable to the positive expected value per economic discovery assessed in figure 16.

Exploration economics is highly sensitive to metal price movements. At upper-limit prices, breakeven costs are reduced to 70 U.S. cents per pound relative to a copper price of 140 U.S. cents per pound, resulting in a healthy net economic return of 70 U.S. cents per pound. However, at the lower-limit copper price of 95 U.S. cents per pound, exploration

24. The evaluation is facilitated by expressing costs and prices per pound of copper equivalent. However, it should be borne in mind that the results implicitly assume relative prices for all the metals as given in table 2.

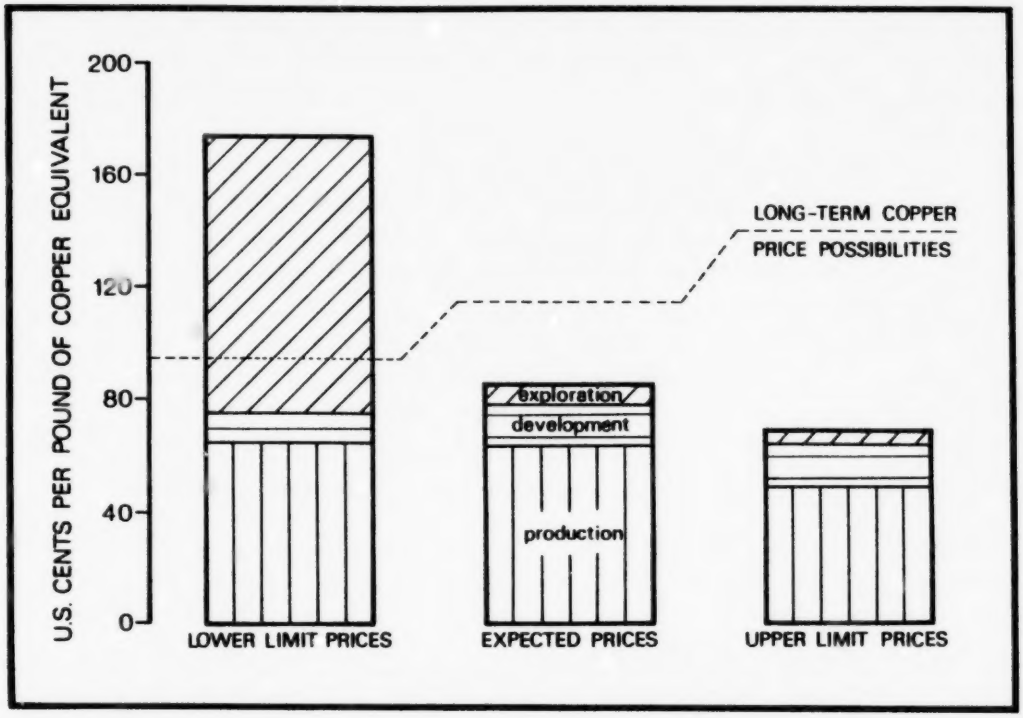

Figure 18. Before-Tax Breakeven Cost and Price Determination

would be decidedly uneconomic with costs totalling 175 U.S. cents per pound. At this level, the price covers little more than production and development costs. Exploration expenditures are very high in this case (100 U.S. cents per pound) because the number of economic deposits is relatively small (see figure 5) and, consequently, exploration costs have to be borne by a relatively small amount of recoverable metal.

Based on the results shown in figure 18, a breakeven copper price of about 105 U.S. cents per pound has been determined. At this point, by definition, costs are also estimated to total 105 U.S. cents per pound. If the long-term copper price is judged to be higher than this critical breakeven price, base metal exploration would be economically justified. Our price projections suggest that there is about a 75-percent chance of this occurring.[25] Otherwise, base metal exploration would be uneconomic.

25. This assumes that the estimated metal price limits specified in table 2 represent 90-percent confidence limits.

Although base metal exploration is shown to be quite economic before tax at expected value prices, it is somewhat disconcerting to note that the expected copper price is only 10 U.S. cents per pound above the breakeven price.[26]

After-tax breakeven cost assessments are presented in figure 19. At expected value prices, breakeven costs increase from 87 U.S. cents per pound of copper equivalent before tax to 107 U.S. cents per pound after tax, squeezing the net economic return from 28 to 8 U.S. cents per pound.[27] Similarly, the economic return is reduced from 70 to 30 U.S. cents per pound at upper-limit prices, and at lower-limit prices the loss is increased from 80 to 110 U.S. cents per pound.

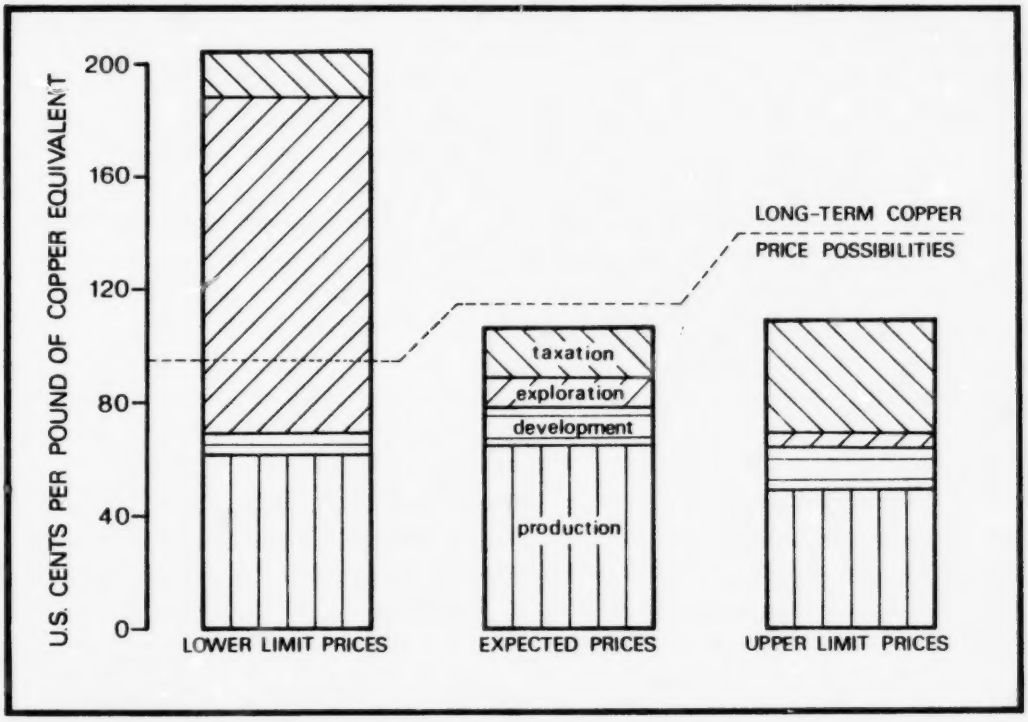

Figure 19. After-Tax Breakeven Cost and Price Determination

26. This price difference should be viewed in relation to future price uncertainties. For example, in September 1982, MacCulloch surveyed 13 Canadian mining companies representing 87 percent of Canada's copper production for the copper price forecasts that they were then using for planning purposes for the next five years. To illustrate, the price estimates for 1986 varied from 70 to 135 constant 1982 U.S. cents per pound. See P.C. MacCulloch, 'The Use of Rate of Return Calculations to Justify Mining Investment

Although the after-tax incentive to invest in base metal exploration is sensitive to price, the tax burden has an offsetting effect. While exploration, development and production costs per pound of recoverable metal generally increase as prices are lowered, taxation costs are reduced. This explains why the breakeven price only increases from 105 U.S. cents per pound before tax to about 110 U.S. cents per pound of copper equivalent after tax. Thus, on an after-tax basis, results indicate that a long-term copper price of at least 110 U.S. cents per pound is required to economically justify base metal exploration for typcial Canadian conditions.

Decisions in Times of Inflation and Volatile Prices - Problems and Suggestions', paper presented at CIM annual meeting, Winnipeg, 1983. This suggests that there is little security associated with the economic justification for exploration shown using expected value prices.

27. This after-tax result is comparable to the expected value per economic discovery presented in figure 17.

7. CONCLUSIONS

Base metal exploration experience in Canada suggests that a large number of economically attractive deposits still await discovery. However, the return or prize to be realized as the result of successful exploration is a very elusive target, due to:

- high risk associated with the discovery of economic deposits;
- geological variability among economic discoveries;
- metal price uncertainties.

The possibility of total loss of exploration funds by a mining company through failure to make an economic discovery is a consequence of the high discovery risk. Persistent exploration over a long investment period and above-average skills are required to insure exploration success.

Geological variability is illustrated by the almost one-hundred-fold difference in value between lower- and upper-decile economic base metal deposits in Canada. Metal price uncertainties have their strongest effect on the number of exploration targets discovered which satisfy economic conditions. For example, as 1983 long-term outlook prices rise from lower-limit to upper-limit levels, the number of economic base metal deposits increases by more than six times. The polymetallic nature of these deposits provides a natural hedge which acts to moderate the consequences of these mineral market risks.

Current mining taxation regimes in Canada, like those which often prevail elsewhere, substantially reduce the value of economic exploration targets from the viewpoint of the mining company. Of greater overall concern is the fact that the Canadian regimes result in a significant reduction in the number of discoveries which meet minimum acceptable economic conditions. The assessment made for base metal exploration targets indicates a 20-percent reduction. This important policy inefficiency not only erodes investment incentive unnecessarily, but also diminishes the wealth created by the mining sector for Canadian society, and lowers long-term government tax revenues.

Time trends in the value of economic exploration targets are shown to be particularly difficult to discern. While results for base metal exploration in Canada are inconclusive, they do not in general support the hypothesis that the economics of mineral exploration is deteriorating with time.

Classification of economic base metal deposits by exploration environment and, more significantly, by deposit type shows fundamental differences in the size and grade of exploration targets and in the metal product mix recoverable from economic deposits.

Results show that the three metals, zinc, copper, and gold, have quite different abilities to convert the in-ground values of exploration targets into actual economic returns. Other things being equal, gold deposits represent more attractive exploration targets than copper deposits, and copper deposits represent more attractive exploration targets than zinc deposits. The same reasoning holds to a lesser degree with respect to the relative mix of metals in polymetallic base metal deposits.

Establishment of minimum acceptable target conditions helps determine whether exploration is economically worthwhile. Minimum acceptable tonnage-grade conditions are presented for gold deposits as a function of gold price and remoteness. These minimum target conditions become increasingly severe as price decreases and as remoteness increases. This does not mean that gold exploration at low prices and in remote areas is necessarily uneconomic. Rather, results indicate that expectations of higher tonnages and grades are required to justify exploration under these circumstances.

The economic justification for exploration is examined by considering the relationship between the value of economic targets, and the exploration time and cost required to realize that value. Assessment of the before-tax expected value of exploration per economic discovery, assuming expected metal prices, suggests that base metal mineral endowment in Canada is of a high quality and has the potential to increase substantially the net value or wealth available to Canadian society. After-tax results, also based on expected prices, indicate that the investment incentive provided for base metal exploration, despite the inefficient burden of present taxation policies, is not unattractive overall.

The assessment of breakeven costs and prices is also used to illustrate the economic justification for base metal exploration in Canada. While results for expected metal prices confirm the positive results evaluated for the expected value of exploration per economic discovery, the breakeven price is 105 U.S. cents per pound of copper equivalent before tax and 110 cents per pound after tax. When viewed in relation to future price uncertainties these results are rather alarming. The breakeven prices lie between the lower-limit copper price of U.S. 95 cents per

pound and the U.S. 115 cents per pound expected price projection. This suggests that there is a significant probability of economic loss associated with base metal exploration.

A practical understanding of the economic characteristics of mineral exploration targets is an important aspect of corporate planning, particularly in terms of the formulation and implementation of exploration strategies.

It also should be stressed that this knowledge should be an equally important ingredient in the development of government mineral policies. Unfortunately, the taxation inefficiencies noted in this paper are but one example of the failure of government policy analysts and decision-makers to recognize these critical features of the mining sector. The negative economic consequences of this policy neglect appear to be important. An increased awareness of the real nature of mineral exploration through quantitative economic assessments will improve the chances of more realistic mineral policy decisions.

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APPENDIX I

CANADIAN BASE METAL DEPOSITS
CLASSIFICATION BY EXPLORATION ENVIRONMENT

Appalachian Region

BRUNSWICK 6
BRUNSWICK 12
BUCHANS
CAPELTON
CAPE RAY
CARIBOU
CLEARWATER
CUPRA
DANIEL'S HARBOUR
EAST
EUSTIS
GAY'S RIVER
GASPE COPPER MOUNTAIN
GREAT BURNET LAKE
GULLBRIDGE
HALFMILE LAKE
HUNTINGTON
KEY ANACON
LITTLE BAY
LITTLE RIVER
MADELEINE
MCLEAN
MING
MURRAY BROOK
NEEDLE MOUNTAIN
ORIENTAL NO. 2
RAMBLER MAIN
ROTHERMERE
SALMON RIVER
SOLBEC
STIRLING
STRATMAT
SUFFIELD
THIRD PORTAGE LAKE
TILT COVE
WALTON
WEDGE
WEEDON
WHALESBACK

Shield Region

AGRICOLA LAKE
ALDERMAC
AMOS
AMULET A
AMULET C
AMULET F
ANDERSON LAKE
ANGLO AMERICAN
BARVALLEE
BARVUE
BELFORT
BELL ALLARD
BIG NAMA CREEK
BIRCH LAKE
BOB
BOUZAN
BRUCE
CAMPBELL MAIN
CEDAR BAY
CENTENNIAL

CHIBOUGAMAU EXPLORERS
CHISEL LAKE
COLDSTREAM
CONIAGAS
COOKE
COPPER CLIFF
COPPERCORP
COPPER-LODE A
COPPER-LODE E
COPPER-MAN
COPPER RAND
CORBET
CORONATION
CUPRUS
DELBRIDGE
DETOUR A1
DETOUR A2
DETOUR B
DICKSTONE
DIXIE
DUNRAINE
EAST SULLIVAN
EAST WAITE
EMBURY LAKE
ERRINGTON
F GROUP
FLEXAR
FLIN FLON
FOX
GARON LAKE
GECO
GHOST LAKE
GOLDEN MANITOU
GRANDROY
GRASSET LAKE
GWILLAM
HACKETT
HENDERSON
HIGH LAKE
HOOD RIVER
HOPE LAKE
HORNE
HYERS ISLAND
ICON
INDIAN MOUNTAIN
IZOK LAKE
JACULET
JAMELAND
JAMIESON
JOLIET
JOUTEL
JUNE
JUNGLE
KAM KOTIA
KIDD CREEK
KOKKO CREEK
LACORNE
LEMOINE
LESSARD
LOST LAKE
LOUVEM
LOUVEM ZINC
LYON LAKE
MAGUSI
MATTABI
MATTAGAMI
MERRILL ISLAND
MILLENBACH
MUNRO COPPER
NANISIVIK
NEW CALUMET
NEW HOSCO
NEW INSCO
NORBEC
NORITA
NORMETAL
NORTH STAR
OLD WAITE
ORCHAN
OSBORNE LAKE
PATER
PERRY
PINEBAY
POIRIER

PORTAGE
PREISSAC
QUEBEC CHIBOUGAMAU
QUEMONT
RAIL LAKE
REED LAKE
RIOCANEX OBALSKI
ROBATAILLE
ROD
RUTTAN
SCHIST LAKE
SCHUMACHER COPPER
SCOTT
SHERRIDON
SOUTH BAY
SPRINGER
SPRUCE POINT
STALL
STURGEON
SYLVIA
TEMAGAMI
TRIBAG
TURNBACK
VAMP LAKE
VAUZE
VENDOME
VERMILLION
WADEN BAY
WAITE DUFAULT
WESTARM
WEST MACDONALD
WHITE LAKE
WILLECHO
WILLROY
WIM

Cordilleran Region

ADANAC
AFTON
ANNEX
ANNIV
BEAR TWIT
BELL
BENSON
BERG
BEST CHANCE
BETHLEHEM
BIG BULL & TULSEQUAH CHIEF
BLUEBELL
BLUE GROUSE
BONANZA
BOSS MOUNTAIN
BRENDA
BRITANNIA
CARIBOO BELL
CASINO
CATFACE
CHUCHUA CREEK
CIRQUE
COPPER MOUNTAIN
COWLEY PARK
CRAIGMONT
DAVIS KEAYS
DY
ENDAKO
FARO
GALORE CREEK
GAYNA RIVER
GEM
GIBRALTAR
GLACIER GULCH
GOLDSTREAM
GRANDUC
GRANISLE
GRUM
HARPER CREEK
HB

HIDDEN CREEK
HIGHMONT
HOWARD'S PASS
HUCKLEBERRY
INDIAN CHIEF
INGERBELLE
ISLAND COPPER
JA
JASON
JERSEY
KEEWENAW
KITSAULT
KUTCHO CREEK
LITTLE CHIEF
LORNEX
LUCKY JIM
LYNX
MAGGIE
MAGNUM
MEL
MINERAL KING
MINTO
MORRISON
MOTHER LODE & SUNSET
MYRA FALLS
NADALEEN RIVER
OK
ORO DENORO
PHOENIX
RED
RED MOUNTAIN
REDSTONE COPPER
REEVES
ROBB LAKE
SAM GOOSLY
SCHAFT CREEK
SILVER GIANT
SNOWSHOE
SULLIVAN
SUNRO
SUSTUT
SWIM LAKE
TOM
TROJAN
TROUT LAKE
VALLEY COPPER
VANGORDA
WAR EAGLE

Other Regions

CORONET
ECLIPSE
GREAT SLAVE REEF
PINE POINT 1
PINE POINT 2
PINE POINT 3
PINE POINT 4
POLARIS
PYRAMID

APPENDIX II

CANADIAN BASE METAL DEPOSITS
CLASSIFICATION BY DISCOVERY DATE

Pre-1946 Discoveries

ALDERMAC
AMOS
AMULET A
AMULET C
AMULET F
BEST CHANCE
BIG BULL & TULSEQUAH CHIEF
BOB
BONANZA
BRITANNIA
BRUCE
BUCHANS
CAMPBELL MAIN
CAPELTON
CEDAR BAY
COPPER-MAN
COPPER MOUNTAIN
CUPRUS
DICKSTONE
DUNRAINE
EAST SULLIVAN
ERRINGTON
EUSTIS
FLIN FLON
GASPE COPPER MOUNTAIN
GOLDEN MANITOU
GULLBRIDGE
HIDDEN CREEK
HORNE
HYERS ISLAND
INDIAN CHIEF
JOLIET
KAM KOTIA
KEEWENAW
LACORNE
LITTLE BAY
LUCKY JIM
MERRILL ISLAND
MOTHER LODE & SUNSET
NEEDLE MOUNTAIN
NEW CALUMET
NORMETAL
OLD WAITE
ORO DENORO
PHOENIX
PREISSAC
QUEMONT
RAMBLER MAIN
REEVES
SHERRIDON
SILVER GIANT
SNOWSHOE
SPRINGER
STIRLING
SUFFIELD
SULLIVAN
TILT COVE
TROJAN
TURNBACK
VAMP LAKE
VERMILLION
WAITE DUFAULT
WAR EAGLE
WEEDON
WEST MACDONALD

1946-1953 Discoveries

BARVUE
BELFORT
BIRCH LAKE
BLUEBELL
BLUE GROUSE
BRUNSWICK 6
BRUNSWICK 12
CHIBOUGAMAU EXPLORERS
COLDSTREAM
CONIAGAS
COPPERCORP
COPPER RAND
CORONATION
COWLEY PARK
EAST WAITE
FLEXAR
GECO
GRANDROY
GRANDUC
HB
HUNTINGTON
INDIAN MOUNTAIN
JACULET
JERSEY
KEY ANACON
KOKKO CREEK
MCLEAN
MINERAL KING
MUNRO COPPER
NORTH STAR
OSBORNE LAKE
PINE POINT 1
ROTHERMERE
SCHIST LAKE
TEMAGAMI
TOM
VANGORDA
VENDOME
WADEN BAY
WILLECHO
WILLROY

1954-1961 Discoveries

ANGLO AMERICAN
BARVALLEE
BELL ALLARD
BETHLEHEM
BIG NAMA CREEK
BOUZAN
CARIBOU
CHISEL LAKE
CLEARWATER
COPPER CLIFF
CORBET
CRAIGMONT
CUPRA
FOX
GARON LAKE
GHOST LAKE
GLACIER GULCH
HALFMILE LAKE
HENDERSON
HIGH LAKE
JOUTEL
JUNGLE
KITSAULT
LITTLE CHIEF
LITTLE RIVER
LYNX
MATTAGAMI
MAGNUM
MURRAY BROOK

NANISIVIK
NEW HOSCO
NORBEC
ORCHAN
ORIENTAL NO. 2
PATER
PERRY
PINEBAY
POIRIER
PORTAGE
QUEBEC CHIBOUGAMAU
SCHUMACHER COPPER
SOLBEC
STALL
SUNRO
THIRD PORTAGE LAKE
VAUZE
WALTON
WEDGE
WHALESBACK

1962-1969 Discoveries

ADANAC
ANDERSON LAKE
ANNEX
BELL
BENSON
BERG
BOSS MOUNTAIN
BRENDA
CASINO
CATFACE
CARIBOO BELL
CENTENNIAL
COOKE
COPPER-LODE A
COPPER-LODE E
CORONET
DANIEL'S HARBOUR
DAVIS KEAYS
DELBRIDGE
EAST
ECLIPSE
ENDAKO
FARO
GALORE CREEK
GEM
GIBRALTAR
GRANISLE
GREAT BURNET LAKE
HARPER CREEK
HIGHMONT
HOPE LAKE
HUCKLEBERRY
ICON
INGERBELLE
ISLAND COPPER
JAMELAND
JAMIESON
JUNE
KIDD CREEK
LOUVEM
LORNEX
MADELEINE
MATTABI
MILLENBACH
MORRISON
NORITA
OK
PINE POINT 2
PYRAMID
RAIL LAKE
REDSTONE COPPER
RED MOUNTAIN
REED LAKE
ROBATAILLE
ROD
RUTTAN

SALMON RIVER
SAM GOOSLY
SCHAFT CREEK
SOUTH BAY
STRATMAT
SWIM LAKE
TRIBAG
VALLEY COPPER
WHITE LAKE
WIM

1970-1977 Discoveries

AFTON
AGRICOLA LAKE
ANNIV
BEAR TWIT
CAPE RAY
CHUCHUA CREEK
CIRQUE
DETOUR A1
DETOUR A2
DETOUR B
DIXIE
DY
EMBURY LAKE
F GROUP
GAYNA RIVER
GAY'S RIVER
GOLDSTREAM
GRASSET LAKE
GREAT SLAVE REEF
GRUM
GWILLAM
HACKETT
HOOD RIVER
HOWARD'S PASS
IZOK LAKE
JA
JASON
KUTCHO CREEK
LEMOINE
LESSARD
LOST LAKE
LOUVEM ZINC
LYON LAKE
MAGGIE
MAGUSI
MEL
MING
MINTO
MYRA FALLS
NADALEEN RIVER
NEW INSCO
PINE POINT 3
PINE POINT 4
POLARIS
RED
RIOCANEX OBALSKI
ROBB LAKE
SCOTT
SPRUCE POINT
STURGEON
SUSTUT
SYLVIA
TROUT LAKE
WESTARM

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Brian W. Mackenzie, a native of Winnipeg, was born in 1939. He holds a B.Eng. (Hon.) in mining from McGill University, an M.Sc. in mineral economics from the University of the Witwatersrand, and a doctorate in engineering science (mineral economics) from Columbia University. After working as an engineer in mines in Canada and South Africa, he became an assistant inspector of mining leases for the South African government, and later worked as a mineral economist with Energy, Mines and Resources in Ottawa. Dr. Mackenzie then taught in the Department of Mining and Metallurgical Engineering at McGill University, where he was director of the mining program, until 1977. In January 1978 he became a research associate of the Centre for Resource Studies and a professor in the Department of Geological Sciences at Queen's University. In 1979 Dr. Mackenzie was named distinguished lecturer in mineral economics by the Canadian Institute of Mining and Metallurgy, and in 1983 he received their 'Robert Elver Mineral Economics Award'. He has presented mineral economics seminars in Canada, Australia, Brazil, Chile, South Africa, Tanzania and Indonesia. He is currently interim executive director of the Centre for Resource Studies.

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